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A STRUCTURAL THEORY FOR THE PERCEPTION OF MORSE CODE SIGNALS AND RELATED RHYTHMIC PATTERNS.

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DESCRIPTORS- *LANGUAGE RESEARCH, *COGNITIVE PROCESSES, COGNITIVE TESTS, PATTERNED RESPONSES, THEORIES, INTERNATIONAL MORSE CODE,

THE PRIMARY PURPOSE OF THIS DISSERTATION IS TO DEVELOP A STRUCTURAL THEORY, ALONG FACET-THEORETIC LINES, FOR THE PERCEPTION OF MORSE CODE SIGNALS AND RELATED RHYTHMIC PATTERNS. AS STEPS IN THE DEVELOPMENT OF THIS THEORY, MODELS FOR TWO SETS OF SIGNALS ARE PROPOSED AND TESTED. THE FIRST MODEL IS FOR A SET COMPRISED OF ALL SIGNALS OF THE INTERNATIONAL MORSE CODE (IMC) IN ADDITION TO SOME SIMILAR DOT AND DASH PATTERNS. THE SECOND MODEL IS FOR A SET COMPRISED OF 32 MORSE-LIKE RHYTHMIC PATTERNS IN WHICH THE SILENT INTERVALS BETWEEN THE DOTS AND DASHES CAN BE EITHER SHORT OR LONG. AN EXPERIMENT BY ROTHKOPF SUPPLIES THE DATA USED TO TEST THE FIRST MODEL. AN EXPERIMENT CARRIED OUT BY THE PRESENT INVESTIGATOR PROVIDED THE DATA USED TO TEST THE SECOND MODEL. IN ROTHKOPF'S STUDY 598 AIRMEN (WHO HAD HAD NO PREVIOUS MORSE CODE TRAINING) AWAITING BASIC TRAINING WERE PRESENTED PAIRS OF IMC SIGNALS AND WERE INSTRUCTED TO RESPOND "SAME" OR "DIFFERENT" ON AN IBM ANSWER SHEET TO EACH OF THESE PAIRS ACCORDING TO WHETHER THEY PERCEIVED THE TWO SIGNALS OF THE PAIR TO BE THE SAME OR DIFFERENT. IN THE PRESENT INVESTIGATOR'S EXPERIMENT, 324 FEMALE UNDERGRADUATES AT THE UNIVERSITY OF MICHIGAN ENROLLED IN INTRODUCTORY PSYCHOLOGY COURSES WERE PRESENTED PAIRS OF THE MORSE-LIKE RHYTHMIC PATTERNS, RATHER THAN PAIRS OF IMC SIGNALS, AND WERE INSTRUCTED TO INDICATE WHETHER THEY PERCEIVED THE SIGNALS OF EACH OF THESE PAIRS AS SAME OR DIFFERENT. IN TESTING BOTH MODELS THE PERCENTAGE OF "SAME" RESPONSES TO EACH ORDERED PAIR OF SIGNALS IS USED AS A MEASURE OF THE CONFUSABILITY OF THE SIGNALS OF THE ORDERED PAIR. USING THIS CONFUSABILITY MEASURE, THE FIRST AND SECOND MODELS ARE SHOWN TO BE OVERWHELMINGLY SUPPORTED BY THE DATA. OTHER PATTERNS OF SIGNAL CONFUSION IN THE TWO EXPERIMENTS ARE ALSO DESCRIBED. THIS DISSERTATION APPEARS IN "STUDIES IN LANGUAGE AND LANGUAGE BEHAVIOR, PROGRESS REPORT IV," PUBLISHED BY THE CENTER FOR RESEARCH ON LANGUAGE AND LANGUAGE BEHAVIOR, 220 EAST HURON STREET, ANN ARBOR, MICHIGAN 48108. CHAPTER V, WHICH COMPRISES THE SUMMARY IS NOT INCLUDED. IT IS AVAILABLE ON REQUEST FROM THE AUTHOR AT THE ABOVE ADDRESS. (AUTHOR/AMM)

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ABSTRACT

A STRUCTURAL THEORY FOR THE PERCEPTION OF MORSE CODE SIGNALS AND RELATED RHYTHMIC PATTERNS

By Myron Wish

The primary purpose of this dissertation is to develop a structural theory, along facet-theoretic lines, for the perception of Morse Code signals and related rhythmic patterns. As steps in the development of this theory, models for two sets of signals are proposed and tested. The first model is for a set comprised of all signals of the International Morse Code (IMC) in addition to some similar dot-and-dash patterns. The second model is for a set comprised of 32 Morse-like rhythmic patterns in which the silent intervals between the dots and dashes can be either short or long.

In both models, signal confusability is systematically related to structural interrelations among the signals. This is accomplished in each model by:

(1) Defining an order relation among the signals;

(2) Hypothesizing that for any three signals, x, y, z, if $x < y < z$ or $z < y < x$, then x will be confused more often with y than with z;

(3) Defining certain kinds of betweenness among the signals; and

(4) Hypothesizing that for any three signals x, y, z, if y is between x and z in all of the proposed senses, then x will be confused more often with y than with z.

An experiment by Rothkopf supplies the data used to test the first model. An experiment carried out by the present investigator provides the data used to test the second model. In Rothkopf's study 598 airmen (who had had no previous Morse Code training) awaiting basic training were presented pairs of IMC signals and were instructed to respond "same" or "different" on an IBM answer sheet to each of these pairs according to whether they perceived the two signals of the pair to be the same or different. In the present investigator's experiment, 324 female undergraduates at the University of Michigan enrolled in introductory psychology courses were presented pairs of the Morse-like rhythmic patterns, rather than pairs of IMC signals, and were instructed to indicate whether they perceived the signals of each of these pairs as same or different.

In testing both models the percentage of "same" responses to each ordered pair of signals is used as a measure of the confusability of the signals of that ordered pair. Using this confusability measure, the first and second models are shown to be overwhelmingly supported by the data.

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Other patterns of signal confusion in the two experiments are also described. In both experiments it is observed that (1) signals having the same number of components are confused more often if they differ on the final component than if they differ on any other single component, and (2) if $x < y$, and x has fewer dashes and/or fewer components than y, then x and y are judged to be "same" more often if x is presented before y than if y is presented before x.

In analyzing separately the responses made in the first, middle, and final thirds of the present investigator's experiment, it is discovered that although the number of "same" judgments decreases from the first to the middle to the final portion of the experimental sessions, the patterns of confusion remain quite constant.

After presenting both models and testing the data from both experiments, the models for both sets of signals are integrated into a single, more general structural theory. Finally, some implications of this thesis for future research are discussed.

CHAPTER 2. THE FIRST MODEL

I. The Universe of Content

Consider a set, Δ, whose elements are the two elementary components of Morse Code signals, dot (denoted ".") and dash (denoted "-"). The 2-component signals of the International Morse Code (IMC) -- (..), (.-), (-.), and (--) -- are the four elements of the product set, or Cartesian product, $\Delta\times\Delta$. Likewise, the eight 3-component signals of the IMC are the elements of the product set, $\Delta\times\Delta\times\Delta$. Let μ_1 be the set which is equal to the union of sets Δ, $\Delta\times\Delta$, $\Delta\times\Delta\times\Delta$, $\Delta\times\Delta\times\Delta\times\Delta$, and $\Delta\times\Delta\times\Delta\times\Delta\times\Delta$. The set of all signals in the IMC is a proper subset of μ_1; i.e., all IMC signals are elements of μ_1, but not all elements of μ_1 are in the IMC.

As is the case for signals in the IMC, in all elements of μ_1 the duration of a dash is three times that of a dot, and the interval between adjacent components of a signal has the same duration as a dot. The duration of a dot will be the unit of temporal length for these signals. The <u>temporal length</u> of a signal, which is defined to be the total number of units in that signal, is equal in units to the number of dots in the signal, plus the number of intervals between adjacent components in the signal (one less than the number of components in the signal), plus three times the number of dashes in the signal.

In Table 1 all elements of μ_1 are listed along with their temporal lengths. The alphabetic or numerical equivalents of the IMC signals are also given in the table. The entire set, μ_1, rather than just the 36 IMC signals will be the universe of content for the first model.

TABLE 1

The Signal Universe for Model 1

Signal	International Morse Code Equivalent	Temporal Length in Units	Signal	International Morse Code Equivalent	Temporal Length in Units
•	E	1	• • • • •	5	9
—	T	3	• • • • —	4	11
			• • • — •		11
• •	I	3	• • — • •		11
• —	A	5	• — • • •		11
— •	N	5	— • • • •	6	11
— —	M	7	• • • — —	3	13
			• • — • —		13
• • •	S	5	• • — — •		13
• • —	U	7	• — • • —		13
• — •	R	7	• — • — •		13
— • •	D	7	• — — • •		13
• — —	W	9	— • • • —		13
— • —	K	9	— • • — •		13
— — •	G	9	— • — • •		13
— — —	O	11	— — • • •	7	13
			• • — — —	2	15
• • • •	H	7	• — • — —		15
• • • —	V	9	• — — • —		15
• • — •	F	9	• — — — •		15
• — • •	L	9	— • • — —		15
— • • •	B	9	— • — • —		15
• • — —		11	— • — — •		15
• — • —		11	— — • • —		15
• — — •	P	11	— — • — •		15
— • • —	X	11	— — — • •	8	15
— • — •	C	11	• — — — —	1	17
— — • •	Z	11	— • — — —		17
• — — —	J	13	— — • — —		17
— • — —	Y	13	— — — • —		17
— — • —	Q	13	— — — — •	9	17
— — — •		13	— — — — —	Ø	19
— — — —		15			

II. The Structural Hypotheses

A. The First Hypothesis

An ordering of the signals in terms of temporal length is defined below. This definition takes into account the precise sequence of dots and dashes in the signals.

Definition 1.

For all $x, y \in \mu_1$, $\underline{x < y}$ if and only if (iff) it is possible to transform x to y by applying to x one or both of the following operations:

(1) changing at least one dot to a dash;

(2) adding at least one component.

If x and y have the same number of components, then according to the definition, $x < y$ iff the duration of each component of x is less than or equal to the duration of the corresponding component of y, and the duration of at least one component of x is less than the duration of the corresponding component of y; i.e., iff x is <u>weakly dominated</u> by y.

Examples:

1. Let x = (..-) and y = (---).

Since x can be transformed to y by changing its first and second components to dashes, (..-) < (---).

2. Let x = (--.) and y = (---..).

Since x can be transformed to y by adding to x a dash at the beginning and a dot at the end (and in many other ways also), (--.) < (---..).

3. Let x = (-..) and y = (.--.).

Although it is not possible to transform x to y by applying only one of the operations above, it is possible to do so by changing the second component of x to a dash (the first operation) and adding a dot at the beginning of x (the second operation). Therefore (-..) < (.--.).

Since not all signals are comparable, e.g., neither (..-) < (--.) nor (--.) < (..-), and neither (.--) < (....-) nor (....-) < (.--), Definition 1 establishes only a partial order on μ_1.

Definition 2.

For all x, y ε μ_1, y is an *immediate successor* of x iff x < y, and there is no z ε μ_1 such that x < z < y.

It follows from this definition that y is an immediate successor of x iff x can be transformed to y by either changing *one* of x's dots to a dash or by adding *one* dot to x.

Definition 3.

For all x, y, z ε μ_1 y is *immediately bounded* by x and z iff one of the following is true:

(1) y is an immediate successor of x, and z is an immediate successor of y; or

(2) y is an immediate successor of z, and x is an immediate successor of y.

Thus, since (...-) is an immediate successor of (..-) and (..-) is an immediate successor of (...), (..-) is immediately bounded by (...) and (...-), or equivalently, (..-) is immediately bounded by (...-) and (...). Definitions 2 and 3 will be utilized at later points in this paper.

Definition 4.

For all x, y, z ε μ_1, *x is closer to y than to z in the ordering on* μ_1 iff x < y < z or z < y < x.

Due to the symmetry of this definition, x is closer to y than to z in the ordering on μ_1 iff z is closer to y than to x in the ordering on μ_1. Since (..-) < (....-) < (..---), (..-) is closer to (....-) than to (..---) in the ordering on μ_1, and (..---) is closer to (....-) than to

(..-) in the ordering on μ_1. Having defined a notion of relative closeness for signals, we are now prepared to state the first hypothesis.

Hypothesis 1.

If x is closer to y than to z in the ordering on μ_1, then x will be confused more often with y than with z.

For example, it is predicted that (..-) will be confused more often with (....-) than with (..---), and that (..---) will be confused more often with (....-) than with (..-).

B. The Second Hypothesis

In the first hypothesis a correspondence between relative closeness in the ordering on μ_1 and relative confusability was proposed. In the second hypothesis predictions of relative confusability are made on the basis of some other structural properties of the signals. For example, two of the predictions that follow from the second hypothesis are that (..-) will be confused more often with (.--) than with (--.), and that (--.) will be confused more often with (-..) than with (..-). An intuitive justification for these predictions is that whereas (.--) differs from (..-) only on the second component and differs from (--.) only in terms of an inversion of the first and third components, (..-) differs from (--.) in both respects. In general, if x differs from z in every respect that it differs from y and in some other respects as well, then x should be confused more often with y than with z.

I shall now proceed to give a more formal basis for the hypothesis of which this prediction is a special case.

Definition 5.

For all x, y, z ε μ_1, <u>y is component-wise between x and z</u> iff:

(1) x, y and z have the same number of components, and

(2) for all i, the i^{th} component of y is the same as the i^{th}

component of x and/or the i^{th} component of z; i.e., each component of y is the same as the corresponding component of x and/or z.[1]

Examples:

1. Let x = (..-), y = (.--) and z = (--.).

Since all three signals have 3 components, the first condition of the definition is satisfied. The second condition is also satisfied, since the first component of y is the same as the first component of x, the second component of y is the same as the second component of z, and the third component of y is the same as the third component of x. Therefore, (.--) is component-wise between (..-) and (--.).

2. Let x = (.--.), y = (....), and z = (-..-).

Since both conditions are satisfied, (....) is component-wise between (.--.) and (-..-).

3. Let x = (.....), y = (...--), and z = (..---).

Since the two conditions are satisfied, (...--) is component-wise between (.....) and (..---).

4. Let x = (.....), y = (-....), and z = (...--).

Since the first component of y differs from the first component of both x and z, (-....) is <u>not</u> component-wise between (.....) and (...--).

5. Let x = (---..), y = (..---), and z = (.----).

Since the second component of y differs from the second component of both x and z, (..---) is <u>not</u> component-wise between (---..) and (.----).

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[1]This is somewhat similar to Restle's (1961) definition of betweenness.

In the sixth definition d(x) denotes the number of dashes in x.

Thus d(-.--) = 3.

Definition 6.

For all x, y, z $\varepsilon\ \mu_1$, <u>y is dash-wise between x and z</u> iff either

$d(x) \leq d(y) \leq d(z)$ or $d(z) \leq d(y) \leq d(x)$.

Examples:

1. Let x = (..-), y = (.--), and z = (--.).

Since d(x) < d(y), and d(y) = d(z), y is dash-wise between x and z.

2. Let x = (..-), y = (--..), and z = (..---).

Since d(x) < d(y) < d(z), y is dash-wise between x and z. However, since x, y, and z do not all have the same number of components, y is not component-wise between x and z.

3. Let x = (.....), y = (-....), and z = (...--).

Since d(x) < d(y) < d(z), y is dash-wise between x and z. As we have already stated, however, y is not component-wise between x and z.

4. Let x = (.--.), y = (....), and z = (-..-).

Although y is component-wise between x and z, y is not dash-wise between x and z. Observe that y has fewer dashes than both x and z.

One can observe that:

(1) y is component-wise between x and z iff y is component-wise between z and x;

(2) y is dash-wise between x and z iff y is dash-wise between z and x.

(3) y is component-wise and dash-wise between x and y; and,

(4) if x, y, and z have the same number of components, and x is

closer to y than to z in the ordering on μ_1, then y is component-wise and dash-wise between x and z.

In the second hypothesis a correspondence between betweenness in these two senses and relative confusability of the signals is proposed.

Hypothesis 2.

For all x, y, $z \in \mu_1$, $(x \neq y \neq z)$, if

(i) y is component-wise between x and z,

(ii) y is dash-wise between x and z, and in addition,

(iii) neither $x < y < z$ nor $z < y < x$,

then x will be confused more often with y than with z.

The third condition was added in order to prevent hypothesis 2 from overlapping with hypothesis 1. Some predictions which follow from the second hypothesis are:

1. (..-) will be confused more often with (.--) than with (--.), and (--.) will be confused more often with (-..) than with (..-).

2. (..---) will be confused more often with (---..) than with (--...), and (--...) will be confused more often with (---..) than with (..---).

3. (.--.) will be confused more often with (-.-.) than with (-..-), and (-..-) will be confused more often with (-.-.) than with (.--.).

If condition (ii) were omitted, we would predict on the basis of hypothesis 2, that (.--.) would be confused more often with (....) than with (-..-). Intuitively, however, since (.--.) and (-..-) have the same combination of dots and dashes, they appear to be quite similar to each other, perhaps even more similar to each other than (....) is to either of these two signals. Thus the second condition prevents us from making such counter-intuitive predictions.

Although many other structural interrelations among the signals could provide the bases for other hypotheses, only these will be considered here. Data obtained by Rothkopf in the experiment described below will be used to test those hypotheses. Since Rothkopf studied only the 36 signals of the International Morse Code, his data can be applied only to that subset of μ_1.

III. A Test of the First Model

A. Rothkopf's Experimental Design

Procedure. *The Ss of this experiment were exposed to pairs of aural Morse signals sent at a high tone speed. The signals of each pair were separated by a short temporal interval. The Ss were asked to indicate whether they thought the two signals were the same (or different) by making the appropriate mark on an IBM True-False Answer sheet. Each S was asked to respond in this fashion to 351 different pairs of Morse signals.*

Materials and apparatus. *Eight different lists of 351 stimulus pairs each were used in this experiment. The lists were composed in the following manner. The 36 signals of the Morse code allow 1,260 two-signal permutations to which the objectively correct response is "different" and 36 pairs of signals to which the objectively correct response is "same." The 1,260 "different" pairs were divided randomly into four groups of 315 pairs of signals each. All of the 36 "same" pairs were then added to each of the groups of 315 pairs. Each list was in this manner brought to a total of 351 pairs of signals. The entire process described above was repeated to yield four additional lists, for a total of eight lists. Pairs were then drawn at random without replacement for each list of 351 in order to determine order of presentation.*

Each of the eight lists was recorded on magnetic tape. The signals were generated by a Boehme Automatic Keyer using a tone speed of 20 words per minute. This tone speed means that each signal was sent fast enough to make 20 transmissions of the word "Codex" within 1 min., or that the temporal duration of each dot was .05 sec., that each dash was .15 sec., and that a silent period between elements was .05 sec. The time interval between the signals of each pair was 1.4 sec., with 3.00 sec. between pairs. To help S keep place on the response sheet an interval of 4.6 sec. was interposed after every tenth pair of signals. A tape-recorded modification of the instructions used with the Signal Corps Code Aptitude Test preceded each list.

The output of a tape recorder carrying the experimental stimuli was, after further amplification, fed to loudspeakers which were mounted in the ceiling of the experimental chamber. This room was judged by E to have good acoustical characteristics. The signals were thought to be of comparable audibility throughout the room. Although the experiment was carried on during the month of July in southern Texas, the experimental room was not air-conditioned.

Subject and design. The Ss of this experiment consisted of 598 airmen awaiting basic training at Lackland AFB. The number was composed of eight separate marching units. These units ranged in size from 51 to 120 men. The Ss who reported Morse code experience were not used. Each of the eight marching units was assigned to a different list of stimulus pairs (Rothkopf, 1957, pp. 95-96).

B. A Restatement of the Hypotheses

In Rothkopf's experiment, as in most auditory experiments, the signals of a pair were presented sequentially rather than simultaneously. Therefore, (x,y), the ordered pair in which x precedes y, is not identical

to (y,x), the ordered pair in which y precedes x. Since (x,y) and (y,x) are distinct, p(x,y) — the percentage of "same" responses to the ordered pair, (x,y) -- may be quite different from p(y,x).

There are 36 pairs of Morse Code signals of the form (x,x). In each of these pairs the first and second signal are the same. Since each signal is structurally more similar to itself than to any other signal, we should expect p(x,x) to be greater than both p(x,y) and p(y,x) for all $x \neq y$.

Rothkopf's data can be used to test the hypotheses of this model, for if it follows from either hypothesis that x will be confused more often with y than with z, then p(x,y) and p(y,x) should both be greater than p(x,z) and p(z,x). In other words, if it is predicted that x will be confused more often with y than with z, then, x and y should be judged to be "same" more often than x and z, irrespective of the order in which the signals are presented.

The hypotheses will now be restated in terms of the percentages of "same" responses to the pairs of Morse Code signals.

Hypothesis 1.

For all x, y, z ε IMC, if x is closer to y than to z in the ordering on μ_1, then:

$p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

Hypothesis 2.

For all x, y, z ε IMC ($x \neq y \neq z$), if

(i) y is component-wise between x and z,

(ii) y is dash-wise between x and z, and in addition,

(iii) neither $x < y < z$ nor $z < y < x$, then

$p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

Although the predictions that follow directly from the hypotheses always involve pairs having one signal in common, there are many derivative predictions of the form $p(x,y) > p(w,z)$. For example, since (...) is closer to (-..) then to (--.) in the ordering on μ_1, it is predicted that p(..., -..) will be greater than p(..., --.); and since (--.) is closer to (...) than to (..) in the ordering on μ_1, it is predicted that p(..., --.) will be greater than p(.., --.). From these two predictions it follows that p(..., -..) should be greater than p(.., --.). In general, if $w < x < y < z$, then $p(x,y)$ and $p(y,x)$ should both be greater than $p(w,z)$ and $p(z,w)$.

Since there are over 10,000 predictions which follow from the hypotheses, it is desirable to have these predictions organized in some meaningful fashion. In the next section I shall attempt to do this.

C. Simplexes and Double Simplexes in Rothkopf's Data Matrix

Rothkopf's data can be summarized in a 36 x 36 matrix whose rows indicate the signal presented first, whose columns indicate the signal presented second, and whose cells indicate the percentage of "same" responses to the corresponding ordered pairs. (Rothkopf's data matrix will be shown in the next section of this chapter.) The 36 cells along the main diagonal of such a matrix indicate the percentage of "same" responses to pairs in which the two signals are identical. If it is true that $p(x,x)$ is greater than $p(x,y)$ for all $x \neq y$, then each diagonal cell should be greater than every other cell in its row; and if it is true that $p(x,x)$ is greater than $p(y,x)$ for all $x \neq y$,

then each diagonal cell should be greater than every other cell in its column. The 1260 cells which are not on the main diagonal indicate the percentages of "same" responses to the pairs in which the first and second signals are different, i.e., the percentages of confusions between the signals of these ordered pairs.

Some implications of the hypotheses for the structure of some selected submatrices of Rothkopf's data matrix are as follows.

(1) If $w < x < y < z$, then the percentages in the submatrix whose rows and columns are ordered w,x,y,z,... should taper off in the direction above and/or to the right of the main diagonal as well as in the direction below and/or to the left of the main diagonal. A matrix (or submatrix) with such a structure will be referred to as a simplex (Guttman; 1954; 1966).

For example, since (...) < (-..) < (--..) < (--.-), it is predicted that the submatrix whose rows and columns are ordered (...), (-..), (--..), (--.-) (or in terms of the alphabetic equivalents, the submatrix whose rows and columns are ordered S,D,Z,Q) will be a simplex. In order for this matrix to have such a structure it is necessary and sufficient that the following inequalities be satisfied:

$p(S,S) > p(S,D) > p(S,Z) > p(S,Q);$

$p(S,S) > p(D,S) > p(Z,S) > p(Q,S);$

$p(D,D) > p(D,Z) > p(D,Q);$

$p(D,D) > p(Z,D) > p(Q,D);$

$p(D,D) > p(D,S);$

$p(D,D) > p(S,D);$

$p(Z,Z) > p(Z,Q);$

$p(Z,Z) > p(Q,Z);$

$p(Z,Z) > p(Z,D) > p(Z,S)$

p(Z,Z) > p(D,Z) > p(S,Z)

p(Q,Q) > p(Q,Z) > p(Q,D) > p(Q,S)

p(Q,Q) > p(Z,Q) > p(D,Q) > p(S,Q)

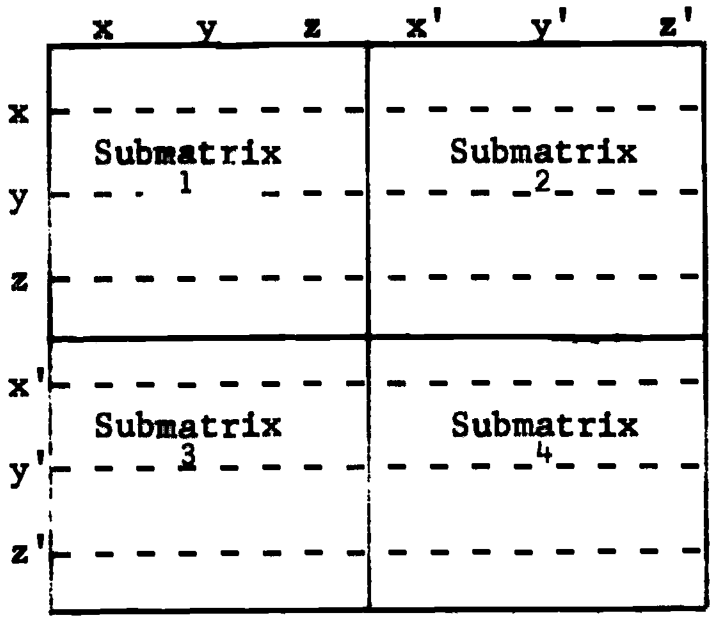
(2) If (i) x, y, z, x', y', and z' all have the same number of components,

(ii) x < y < z and x' < y' < z',

(iii) x, y, and z have the same combination of dots and dashes as x', y', and z', respectively, and

(iv) x, y, and z differ from x', y', and z', respectively on exactly the same components,

then the submatrix whose rows and columns are ordered x, y, z, x', y', z'; namely,



should be a double simplex (Wish, 1965); i.e.,

(i) the submatrix whose rows and columns are ordered x,y,z (submatrix 1) should be a simplex;

(ii) the submatrix whose rows are ordered x,y,z and whose columns are ordered x', y', z' (submatrix 2) should be a simplex;

(iii) the submatrix whose rows are ordered x', y', z' and whose columns are ordered x, y, z (submatrix 3) should be a simplex;

(iv) the submatrix whose rows and columns are ordered x', y', z' (submatrix 4) should be a simplex;

(v) if submatrix 1 is superimposed upon either submatrix 2 or 3, then each cell value in submatrix 1 should be greater than the cell value upon which it is superimposed; and

(vi) if submatrix 4 is superimposed upon either submatrix 2 or 3, then each cell value in submatrix 4 should be greater than the cell value upon which it is superimposed.

Example:

Let x = (-...), y = (--..), z = (--.-)

x' = (..-.), y' = (.--.), and z' = (.---).

Since (i) all six of these signals have four components;

(ii) $x < y < z$ and $x' < y' < z'$;

(iii) x, y, and z have the same combination of components as x', y', and z', respectively; and

(iv) x differs from x', y differs from y', and z differs from z' on the same components--the first and third--

it is predicted that the submatrix whose rows and columns are ordered (-...), (--..), (--.-), (..-.), (.--.), (.---) -- B,Z, Q,F,P,J -- should be a double simplex.

IV. Results and Discussion

A. The Hypotheses

Rothkopf's data appear in Table 2 as well as in Table 3. These two matrices differ only in terms of a permutation of the rows and columns. The cell values in these matrices indicate the percentages of "same" responses given to each ordered pair of Morse Code signals. Thus, 62 per cent of the Ss who were presented the ordered pair (D,B) responded "same."

Table 2 Per Cent "Same" Judgments Obtained by Rothkopf for All Ordered Pairs of Signals from the International Morse Code.

I. Signals Grouped According to Temporal Length

	E	I	T	S	A	N	H	U	R	D	M	5	V	F	L	B	W	K	G	4	6	P	X	C	Z	O	3	7	J	Y	Q	2	8	1	9	Ø	
• E	97	17	67	07	06	04	04	03	10	06	04	05	03	02	06	13	02	05	04	03	02	01	05	14	05	05	05	04	01	06	05	03	02	04	03	03	E
•• I	10	93	16	35	64	30	12	10	19	13	13	06	05	08	16	07	08	05	06	09	08	03	02	07	07	07	09	05	03	05	05	05	02	02	04	05	I
— T	46	14	96	07	13	05	06	08	04	05	06	03	05	03	07	10	04	14	06	03	08	11	02	01	06	06	03	07	06	02	04	05	06	05	14	06	T
••• S	11	16	09	96	17	17	59	56	18	30	05	28	24	26	10	24	12	13	05	15	09	06	10	05	07	06	02	05	03	06	03	02	05	08	05	02	S
•— A	03	46	06	23	92	34	13	37	35	13	25	08	13	14	03	04	17	22	10	05	06	06	12	06	03	06	05	05	05	07	09	07	06	02	02	03	A
—• N	08	13	10	12	31	93	16	16	28	30	59	04	04	12	08	04	12	16	10	04	06	09	04	13	11	05	03	02	03	06	05	02	02	05	10	02	N
•••• H	09	10	04	37	03	08	87	36	17	25	05	70	59	32	29	45	09	09	08	43	35	14	33	23	11	08	15	17	10	14	08	09	04	03	03	03	H
••— U	04	21	06	51	14	13	11	93	40	32	11	10	57	32	32	29	34	44	11	34	09	20	17	12	11	06	16	09	07	09	12	06	07	06	04	03	U
•—• R	05	07	02	16	13	12	15	23	87	23	14	07	23	34	37	14	62	21	26	04	12	29	14	16	13	12	13	07	12	12	08	10	09	07	01	02	R
—•• D	07	09	07	29	08	07	36	17	45	88	08	09	20	23	56	62	27	81	40	11	19	27	40	17	33	09	06	08	13	15	09	09	10	03	05	06	D
—— M	07	08	09	07	24	62	08	13	20	14	96	05	04	17	08	12	21	23	29	06	07	10	09	05	08	11	06	11	11	18	15	07	07	05	10	04	M
••••• 5	02	07	02	27	08	00	67	14	09	14	02	90	45	45	41	45	07	04	04	69	42	13	45	15	10	04	30	24	14	10	07	10	10	14	06	05	5
•••— V	09	05	06	11	05	01	39	32	17	16	04	44	92	29	43	17	17	26	06	79	36	17	57	24	10	09	28	25	11	35	10	14	10	10	01	05	V
••—• F	02	05	02	14	04	06	29	21	35	19	07	26	27	90	50	51	25	16	10	25	24	42	19	33	13	10	47	21	33	27	12	16	05	08	05	03	F
•—•• L	10	09	05	12	02	02	26	16	28	45	06	26	19	24	86	69	20	27	12	15	29	37	31	43	59	09	17	36	30	25	36	13	16	12	07	03	L
—••• B	05	05	02	18	05	10	21	18	16	31	06	32	34	28	40	84	08	34	17	40	74	22	84	37	42	12	14	43	19	30	25	17	17	12	04	04	B
•—— W	09	04	04	12	09	06	15	19	61	22	15	05	20	36	18	21	86	29	25	16	09	20	22	30	22	26	19	11	25	25	25	22	06	10	03	07	W
—•— K	01	05	02	02	05	12	11	23	22	73	10	08	17	17	33	24	33	91	25	08	18	14	63	38	18	31	17	14	27	16	31	09	13	05	05	06	K
——• G	01	05	03	05	09	13	06	15	21	38	14	04	14	14	16	18	32	33	90	10	10	52	21	27	39	82	05	17	22	23	23	14	23	15	20	11	G
••••— 4	06	07	03	09	06	03	16	17	11	12	03	42	55	25	19	19	08	13	14	89	44	17	37	19	03	02	44	32	21	24	29	26	10	05	03	03	4
—•••• 6	04	02	03	14	07	02	14	12	11	17	06	17	30	23	27	80	09	11	04	24	86	16	58	30	39	07	26	69	11	38	30	14	14	15	05	14	6
•——• P	05	03	04	09	05	06	12	12	23	12	05	15	19	36	46	22	19	14	22	11	17	83	19	33	30	21	24	24	78	41	43	44	23	34	25	13	P
—••— X	03	01	03	12	07	08	06	12	10	19	10	16	17	28	42	64	21	50	11	27	57	32	91	45	26	24	24	29	35	48	61	20	16	12	17	06	X
—•—• C	04	11	06	14	04	03	07	06	24	17	14	10	11	29	35	38	14	24	13	14	30	51	32	87	38	09	31	28	19	82	34	15	24	13	18	12	C
——•• Z	02	07	03	04	03	02	10	09	14	18	11	10	11	22	51	46	12	21	17	09	24	59	36	45	87	15	27	66	23	42	72	21	47	16	15	15	Z
——— O	05	02	04	03	07	08	07	11	10	06	04	06	14	09	10	07	25	26	76	07	18	37	35	20	27	86	07	14	39	27	35	17	11	19	20	12	O
•••—— 3	04	02	06	07	03	02	12	04	09	05	05	23	16	32	13	08	06	06	06	31	41	37	22	21	12	05	86	16	23	25	19	64	17	18	08	10	3
——••• 7	05	06	02	06	06	06	04	03	12	14	07	12	13	25	32	33	09	13	06	15	61	36	30	22	50	07	18	85	24	30	39	29	70	22	20	13	7
•——— J	02	04	07	03	07	05	09	11	09	08	07	07	09	24	31	09	09	22	18	15	11	63	22	38	28	21	33	28	85	32	47	66	29	67	26	23	J
—•—— Y	04	01	04	07	09	06	09	06	05	15	05	11	13	26	14	23	21	12	22	15	11	30	44	62	23	14	40	22	30	86	52	44	33	26	23	16	Y
——•— Q	04	05	03	02	08	06	05	06	11	11	07	09	14	15	26	20	12	23	10	12	27	51	37	38	63	22	17	40	27	50	91	32	58	34	37	24	Q
••——— 2	04	25	03	05	07	03	03	06	06	05	02	05	10	20	14	14	11	09	13	20	14	17	37	22	13	17	54	20	26	30	28	89	21	62	16	11	2
———•• 8	03	02	04	06	03	06	06	06	02	06	03	09	07	15	14	23	05	10	15	16	30	24	12	40	50	14	16	60	33	35	45	29	89	42	61	26	8
•———— 1	03	02	02	04	02	07	04	03	09	03	09	10	12	05	14	05	14	05	13	08	08	30	17	10	22	14	13	19	29	19	28	63	32	84	57	55	1
————• 9	01	02	07	06	03	11	05	06	05	03	16	04	03	06	07	14	09	06	14	12	11	11	31	23	24	10	09	42	30	21	32	29	56	57	91	78	9
————— Ø	05	05	04	03	09	03	04	05	02	02	02	05	03	07	07	03	02	08	14	11	22	02	21	11	20	05	09	17	30	15	29	26	52	50	81	94	Ø
	E	I	T	S	A	N	H	U	R	D	M	5	V	F	L	B	W	K	G	4	6	P	X	C	Z	O	3	7	J	Y	Q	2	8	1	9	Ø	

Table 3 Per Cent "Same" Judgments Obtained by Rothkopf for All Ordered Pairs of Signals from the Morse Code.

II. Signals Grouped According to Number of Components

	E	T	I	A	N	M	S	U	R	D	W	K	G	O	H	V	F	L	B	P	X	C	Z	J	Y	Q	5	4	6	3	7	2	8	1	9	Ø	
· E	97	67	17	06	04	04	07	03	16	06	02	05	04	05	04	03	02	06	13	01	05	14	05	01	06	05	05	03	02	05	04	03	02	04	03	03	E
— T	46	96	14	13	05	06	07	08	04	05	04	14	06	06	06	05	03	07	10	11	02	01	06	06	02	04	03	03	08	03	07	05	06	05	14	06	T
· · I	10	16	93	64	30	13	35	10	19	13	08	05	06	07	12	05	08	16	07	03	02	07	07	03	05	05	06	09	08	08	05	05	02	02	04	05	I
· — A	03	06	46	92	34	25	23	37	35	13	17	22	10	06	13	13	14	03	04	06	12	06	03	05	07	09	08	05	06	05	05	07	06	02	02	30	A
— · N	08	10	13	31	93	59	12	16	28	30	12	16	10	05	16	04	12	08	04	09	04	13	11	03	06	05	04	04	06	03	02	02	02	05	10	02	N
— — M	07	09	08	24	62	96	07	13	20	14	21	23	29	11	08	04	17	08	12	10	09	05	08	11	18	15	05	06	07	06	11	07	07	05	10	04	M
· · · S	11	09	16	17	17	05	96	56	18	30	12	13	05	06	59	24	26	10	24	06	10	05	07	03	06	03	28	15	09	02	05	02	05	08	05	02	S
· · — U	04	06	21	14	13	11	51	93	40	32	34	44	11	06	34	57	32	32	29	20	17	12	11	07	09	12	10	34	09	16	09	06	07	06	04	03	U
· — · R	05	02	07	13	12	14	16	23	87	23	62	21	26	12	15	23	34	37	14	29	14	16	13	12	12	08	07	04	12	13	07	10	09	07	01	02	R
— · · D	07	06	09	08	07	08	29	17	45	88	27	81	40	09	36	20	23	56	16	27	40	17	33	13	15	09	09	11	19	06	08	09	10	03	05	06	D
· — — W	09	04	04	09	06	15	12	19	61	22	86	29	25	26	15	20	36	18	21	20	22	30	22	25	25	25	05	16	09	19	11	22	06	10	03	07	W
— · — K	01	02	05	05	12	10	02	23	22	73	33	91	25	31	11	17	17	33	24	14	63	38	18	27	16	31	08	08	18	17	14	09	13	05	05	06	K
— — · G	01	03	05	09	13	14	05	15	21	38	32	33	90	82	06	14	14	16	18	52	21	27	39	22	23	23	04	10	10	05	17	14	23	15	20	11	G
— — — O	05	04	02	07	08	04	03	11	10	06	25	26	76	86	07	14	09	10	07	37	35	20	27	39	27	35	06	07	18	07	14	17	11	19	20	12	O
· · · · H	09	04	10	03	08	05	37	36	17	25	09	09	08	08	87	59	32	29	45	14	33	23	11	10	14	08	70	43	35	15	17	09	04	03	03	03	H
· · · — V	09	06	05	05	01	04	11	32	17	16	17	26	06	09	39	92	29	43	17	17	57	24	10	11	35	10	44	79	36	28	25	14	10	10	01	05	V
· · — · F	02	02	05	04	06	07	14	21	35	19	25	16	10	10	29	27	90	50	51	42	19	33	13	33	27	12	26	25	24	47	21	16	05	08	05	05	F
· — · · L	10	05	09	02	02	06	12	16	28	45	20	27	12	09	26	19	24	86	69	37	31	43	59	30	25	36	26	15	29	17	36	13	16	12	01	03	L
— · · · B	05	02	05	05	10	06	18	18	16	31	08	34	17	12	21	34	28	40	84	22	84	37	42	19	30	25	32	40	74	14	43	17	17	12	04	04	B
· — — · P	05	04	03	05	06	05	09	12	23	12	19	14	22	21	12	19	36	46	22	83	19	33	30	78	41	43	15	11	17	24	24	44	23	34	25	13	P
— · · — X	03	03	01	07	08	10	12	12	10	12	21	50	11	24	06	17	28	42	64	32	91	45	26	35	48	61	16	27	51	24	29	20	16	12	17	06	X
— · — · C	04	06	11	04	03	14	14	06	24	17	14	24	13	09	07	11	29	35	38	51	32	87	38	19	82	34	10	14	30	31	28	15	24	13	18	12	C
— — · · Z	02	03	07	03	02	11	04	09	14	18	12	21	17	15	10	11	22	51	46	59	36	45	87	23	42	72	10	09	25	27	66	21	47	16	15	15	Z
· — — — J	02	07	04	07	03	08	02	09	11	09	09	22	18	21	05	09	24	31	09	63	22	38	28	85	32	47	07	15	11	33	28	66	29	67	26	23	J
— · — — Y	04	04	01	09	06	05	07	06	05	15	21	12	22	14	09	13	26	14	23	30	44	62	23	30	86	52	11	15	26	40	22	44	33	26	23	16	Y
— — · — Q	04	03	02	08	06	07	02	06	11	11	12	23	10	22	05	14	15	26	20	51	37	38	63	27	50	91	09	12	26	17	40	32	58	34	37	24	Q
· · · · · 5	02	02	07	08	00	02	27	14	09	14	07	04	04	04	67	45	45	41	45	13	45	15	10	14	10	07	90	69	42	30	24	10	10	14	06	05	5
· · · · — 4	06	03	07	06	03	03	09	17	11	12	08	13	14	02	16	55	25	19	19	17	37	19	03	21	24	29	42	89	44	44	32	26	10	05	03	03	4
— · · · · 6	04	03	02	07	02	06	14	12	11	17	09	11	04	07	14	30	23	27	80	16	58	30	39	11	38	30	17	24	86	26	69	14	14	15	05	14	6
· · · — — 3	04	06	02	03	02	05	07	04	09	05	06	06	06	05	12	16	32	13	08	37	22	21	12	23	25	19	23	31	41	86	16	64	17	18	08	10	3
— — · · · 7	05	02	06	06	06	07	06	03	12	14	09	13	06	07	04	13	25	32	33	36	30	22	50	24	30	39	12	15	61	18	85	29	70	22	20	13	7
· · — — — 2	04	03	25	07	03	02	05	06	06	05	11	09	13	17	03	10	20	14	14	37	17	22	13	26	30	28	05	20	14	54	20	89	21	62	16	11	2
— — — · · 8	03	04	02	03	06	03	06	06	02	06	05	10	15	14	06	07	15	14	23	12	24	40	50	33	35	45	09	16	30	16	60	29	89	42	61	26	8
· — — — — 1	03	02	02	02	07	09	04	03	09	03	14	05	13	14	04	12	05	14	05	30	17	10	22	29	59	28	10	08	08	13	19	63	32	84	57	55	1
— — — — · 9	01	07	02	03	11	16	06	06	05	03	08	06	14	10	05	03	06	07	14	31	11	23	24	30	21	32	04	12	11	09	42	39	56	57	91	78	9
— — — — — Ø	05	04	05	09	03	02	03	05	02	02	02	08	14	25	04	03	07	03	03	21	12	11	20	30	15	29	05	11	22	09	17	26	52	50	81	94	Ø
	E	T	I	A	N	M	S	U	R	D	W	K	G	O	H	V	F	L	B	P	X	C	Z	J	Y	Q	5	4	6	3	7	2	8	1	9	Ø	

One can observe in either Table 2 or Table 3 that, with only one exception, each diagonal cell is greater than every other cell in its row and column. The exception occurs in B's row, for p(B,X) = p(B,B).

Since the values in Tables 2 and 3 tend to decrease in the directions away from the main diagonal, we can anticipate that hypothesis 1 will receive some support. All of the predictions that follow directly from the first hypothesis are based upon a particular relationship among the signals--x is closer to y than to z in the ordering on μ_1. In some instances y is immediately bounded by x and z, while in other instances this is not the case, i.e., y is <u>not</u> immediately bounded by x and z. On the basis of this dichotomy I shall divide the predictions following from hypothesis 1 into two classes. In the first class are those predictions in which y is immediately bounded by x and z. The predictions in which y is not immediately bounded by x and z are in the second class.

Of the 1240 predictions in the first class 1174, (95%) are correct. Since there are several thousand predictions in the second class, only a sample of 2000 were tested. Of the 2000 predictions 1646, (82%) are in accord with the data. However, of the 354 errors of predictions very few involve a difference greater than 3%. In fact, in 114 of these 354 cases the percentage that was predicted to be greater than another percentage is equal to that other percentage.

In order to get a better perspective of the support for, as well as the limitations on hypothesis 1, it is helpful to study some of the matrices that were predicted to be simplexes. In Table 4 two such matrices are displayed. Observe that the percentages taper off in the directions away from the main diagonal. A close look reveals that within the region of the upper matrix determined by the pair of dotted

TABLE 4

Two Approximate Simplexes in Rothkopf's Data Matrix

		E	I	S	H	5	6	7	8	9	Ø
·	E	97	17	07	04	05	02	04	02	03	03
· ·	I	10	93	35	12	06	08	05	02	04	05
· · ·	S	11	16	96	59	28	09	05	05	05	02
· · · ·	H	09	10	37	87	70	35	18	04	03	03
· · · · ·	5	02	07	27	67	90	42	28	10	06	05
– · · · ·	6	04	02	14	14	17	86	69	14	05	14
– – · · ·	7	05	06	06	04	12	61	85	70	20	13
– – – · ·	8	03	02	06	06	09	30	60	89	61	26
– – – – ·	9	01	02	06	05	04	11	42	56	91	78
– – – – –	Ø	05	05	03	04	05	22	17	52	81	94

		E	T	A	U	F	C	Y	I	Ø
·	E	97	67	06	03	02	14	06	04	03
–	T	46	96	13	08	05	01	02	05	06
· –	A	03	06	92	37	14	06	07	02	02
· · –	U	04	06	14	93	32	12	09	06	03
· · – ·	F	02	02	04	21	90	33	27	08	05
– · – ·	C	04	06	04	06	29	87	82	13	12
– · – –	Y	04	04	09	06	26	62	86	26	16
· ·	I	03	02	02	03	05	10	19	84	55
– – – – –	Ø	05	04	09	05	07	11	15	50	94

lines there are only two violations of the simplex patterns--p(I,E) < p(S,E), and p(6,S) = p(6,H); and within the region of the lower matrix determined by the pair of dotted lines there are only four violations of the simplex pattern--p(A,E) < p(U,E), p(U,T) = p(A,T), p(C,A) = p(F,A), and p(Y,U) = p(C,U). Outside the bounds of the dotted lines, however, there are several violations. If a percentage, p(x,y), is within the dotted lines, then x and y differ in temporal length by no more than 6 units. If a percentage, p(x,y), is outside the bounds of the dotted lines, then x and y differ in temporal length by 8 or more units. It seems that Ss can almost always detect that signals differing by 8 units are different. Any greater difference in temporal length does not appear to make it any easier for Ss to detect the differences among the signals. Thus, there is little differentiation among the percentages (and therefore, several errors of prediction) outside of the dotted lines.

We shall now turn to a test of the second hypothesis. Of the 880 predictions following directly from this hypothesis 772, (88%) are correct. As in the first hypothesis most of the errors of predictions involve small differences in percentages. Since hypotheses 1 and 2 receive considerable support, the matrices shown in Table 5 are approximately double simplexes. Observe in Table 5 that all four 3x3 submatrices of each matrix have simplex patterns. In a double simplex the values in the two submatrices that contain the main diagonal--submatrices 1 and 4--should be greater than the values in the corresponding cells of the other two submatrices--submatrices 2 and 3. Note that in only two instances is a value in submatrix 1 or 4 as small or smaller than the value in the corresponding cell of submatrix 2 or 3--p(C,F) < p(C,L) and p(F,C) < p(L,C).

TABLE 5

Two Approximate Double Simplexes in Rothkopf's Data Matrix

		B	Z	Q	F	P	J
— • • •	B	84	42	25	28	22	19
• • • •	Z	46	87	72	22	59	23
– • • —	Q	20	63	91_1	$^2 15$	51	27
• • • •	F	51	13	12^3	$^4 90$	42	33
• — • •	P	22	30	43	36	83	78
• — • —	J	09	28	47	24	63	85

		L	Z	Q	F	C	Y
• • • •	L	86	59	36	24	43	25
— • • •	Z	51	87	72	22	45	42
— — • —	Q	26	63	91_1	$^2 15$	38	50
• • — •	F	50	13	12^3	$^4 90$	33	27
— • — •	C	35	38	34	29	87	82
— • — —	Y	14	23	53	26	62	86

B. Other Patterns of Confusion Among the Morse Code Signals

Having tested the hypotheses, I shall now report some additional observations about the patterns of confusion among Morse Code signals. I shall begin by examining the most common types of confusions, ("same" responses to pairs in which the signals are different).

The most habitual kind of confusion is the failure to detect a difference between signals that have the same number of components but differ on a single component. For example, p(...., ...-) = 59% and p(...-, ...) = 39%. There are 88 ordered pairs in which the two signals have the same number of components, but differ on one component. In all pairs in this category the signal with more dashes is a successor of the other signal. The mean confusion rate for these 88 ordered pairs is 47.3%. There is, however, considerable variability in the confusion rate as a function of the order in which the signals of the pair are presented and the particular component on which the signals differ. If y is a successor of x, and x and y have the same number of components, then in 38 of the 44 pairs, p(x,y) is greater than p(y,x); e.g., p(...., ...-) is greater than p(...-, ...). The mean of these p(x,y)'s is 52%, whereas the mean p(y,x) is 42.6%. Thus, on the average, there are 9.4% more confusions when the shorter signal is presented first than when the longer signal is presented first.

Table 6 presents an analysis of the percentage of "same" judgments as a function of the number of components and the particular component on which the signals differ. We can observe in this table that there is a greater likelihood that <u>S</u>s will respond "same" if the difference between the signals occurs on the final component than if the difference is on any other component. An explanaticn for the effect is that the duration of the final component is more ambiguous or indefinite than

TABLE 6

Percentage of "Same" Responses to Pairs of

Signals Which Differ on A Single Component

	Number of Components				
Component on Which Signals Differ	1	2	3	4	5
Final	56.5	57.8	67.8	66.6	67.5
Fourth (but not final)					48.0
Third (but not final)				38.9	62.0
Second (but not final)			27.8	39.9	63.8
First (but not final)		23.0	28.0	39.0	41.0

that of any other component, since the cue concerning the duration of a component provided by the onset of a subsequent component is unavailable. Another thing to note in Table 6 is that as the number of components increases, it becomes harder to detect that signals differ on a particular component.

The second most frequent kind of confusion is with regard to pairs in which the two signals have the same combination of dots and dashes, but differ in terms of an inversion of two components. In this category are confusions among signals of such pairs as (..-, -..) and (-.--, --.-). The average percentage of "same" judgments for the 46 ordered pairs in this category is 36.3%. That signals differing in terms of an inversion of two components are called "different" 63.7% of the time indicates that the precise sequence of dots and dashes, as well as the number of dots and dashes, is of some importance in the judgmental process.

The next most common kind of confusion is the failure to observe that one signal of a pair has one more dot than the other. In order for confusions to be in this category, the signal with the additional dot must be a successor of the other signal. The mean percentage of "same" judgments for the 64 pairs in this category is 32.4%.

The effect which order of presentation has on the percentage of "same" judgments for pairs in this category is even stronger than that reported for signals differing on a single component. In 29 of the 32 cases, if x can be transformed to y by adding a dot to x, then $p(x,y) > p(y,x)$. For example, p(--., .--.) = 52% whereas p(.--., --.) = 22%. The mean $p(x,y)$ is 39.3%, whereas the mean $p(y,x)$ is 25.4%.

We have seen that if y is a successor of x, then in 67 of the 76 instances (38 + 29 / 44 + 32), $p(x,y)$ is greater than $p(y,x)$. This is part of a more general effect of order of presentation -- if $x < y$, then

$p(x,y)$ tends to be greater than $p(y,x)$. However, as the differences in temporal length between x and y increases, this nonsymmetry decreases.

The effect associated with order of presentation is similar to the time-error phenomenon which Postman (1946) observed in loudness discrimination. When the stimuli of a pair were separated by a 1 to 2 second interval, Postman reports that the loudness of the second signal tended to be underestimated. In Rothkopf's experiment the Ss appear to underestimate the duration of and/or number of components in the second signal. Since presenting the shorter signal first attenuates the difference between the signals and presenting the longer signal first exaggerates the difference between the signals, Ss respond "same" more often when the shorter signal precedes the longer signal.

The presentation-order, or "time-error," phenomenon has particular relevance to hypothesis 1. If $x < y < z$, then the following predictions follow from hypothesis 1:

(1) $p(x,y) > p(x,z)$ (5) $p(z,y) > p(z,x)$

(2) $p(x,y) > p(z,x)$ (6) $p(z,y) > p(x,z)$

(3) $p(y,x) > p(z,x)$ (7) $p(y,z) > p(x,z)$

(4) $p(y,x) > p(x,z)$ (8) $p(y,z) > p(z,x)$

According to the presentation-order phenomenon described above if $x < y < z$, then:

(9) $p(x,y) > p(y,x)$,

(10) $p(y,z) > p(z,y)$,

(11) $p(x,z) > p(z,x)$.

These 11 inequalities are combined into the following orderings among the percentages:

$$p(x,y) > p(y,x) > p(x,z) > p(z,x);$$

$$p(y,z) > p(z,y) > p(x,z) > p(z,x).$$

One can observe in Rothkopf's data that if $x < y < z$, then (for a given difference in temporal length between x and y, and between y and z), violations of hypothesis 1 are most likely to occur when p(y,x) or p(z,y) is compared with p(x,z), and violations are least likely to occur when p(x,y) or p(y,z) is compared with p(z,x). In the former cases the "time-error" phenomenon increases the probability of an error of prediction, whereas in the latter cases, the "time-error" phenomenon decreases the probability of an error of prediction. Note above that the difference between p(x,y) and p(z,x) is usually greater than the difference between p(y,x) and p(x,z), and that the difference between p(y,z) and p(z,x) is usually greater than the difference between p(z,y) and p(x,z).

Shepard (1963), in comparing Rothkopf's data with substitution error data obtained by Keller and Taubman (1943) and by Plotkin (1943), points out that the patterns of confusion among Morse Code signals differ considerably from the patterns of substitution errors made by Ss learning the International Morse Code. For example, signals that can be transformed into each other by converting all dots to dashes and vice versa, such as (...) and (---), or (-...) and (.---), are frequently substituted for each other during learning despite the fact that they are rarely confused when presented in immediate succession. Shepard (1963, p. 43) concludes that "the learning task -- unlike Rothkopf's short-term comparison task -- requires the establishment of long-term associative connections. Perhaps in this latter situation, then, the Ss are still able to perceive whether three dots or three dashes were presented. Apparently they can also remember that the two responses assigned to these signals are "S" and "O." What they cannot keep straight is which response goes with which signal." On the basis of the patterns of substitution errors in Plotkin's

and in Keller and Taubman's data, it can be concluded that in this model the number of times each signal is substituted for every other signal cannot be used as a measure of signal confusability.

C. Multidimensional Configurations for the Morse Code Signals

Having discussed some of the most obvious patterns in Rothkopf's data, let us now consider some geometric representations of the data matrix which will make the total structure more comprehensible. All of the configurations which will be presented were obtained by means of nonmetric multidimensional scaling procedures (Kruskal, 1964a, 1964b; Guttman, 1967, in preparation; Lingoes, 1966b, in press). The aim of these procedures is to obtain a configuration of points in a Euclidean space[2] of a specified number of dimensions such that distances between points in the space are monotonic with some set of coefficients. Since the coefficients in Rothkopf's matrix, the percentages, can be assumed to be measures of similarity (rather than dissimilarity), the distances should be a monotonic decreasing function of these coefficients. The stress of the configuration (Kruskal, 1964a), or the coefficient of alienation (Lingoes, 1966a), is a normalized residual sum of squared deviations from perfect monotonicity. Thus the lower the stress, or coefficient of alienation, the more adequately the configuration reflects the structure of the data matrix.

Shepard (1963) obtained the configuration shown in Fig. 1 (stress = .18) by applying Kruskal's (1964) program (using the symmetric option) to Rothkopf's data. The input to the computer was the symmetric matrix appearing on page 97 of Rothkopf's (1957) paper. In order to obtain the symmetric matrix Rothkopf averaged the two symmetrically situated cells

[2]The Kruskal program can give a solution in terms of any specified Minkowski Λ-metric (Kruskal, 1964b).

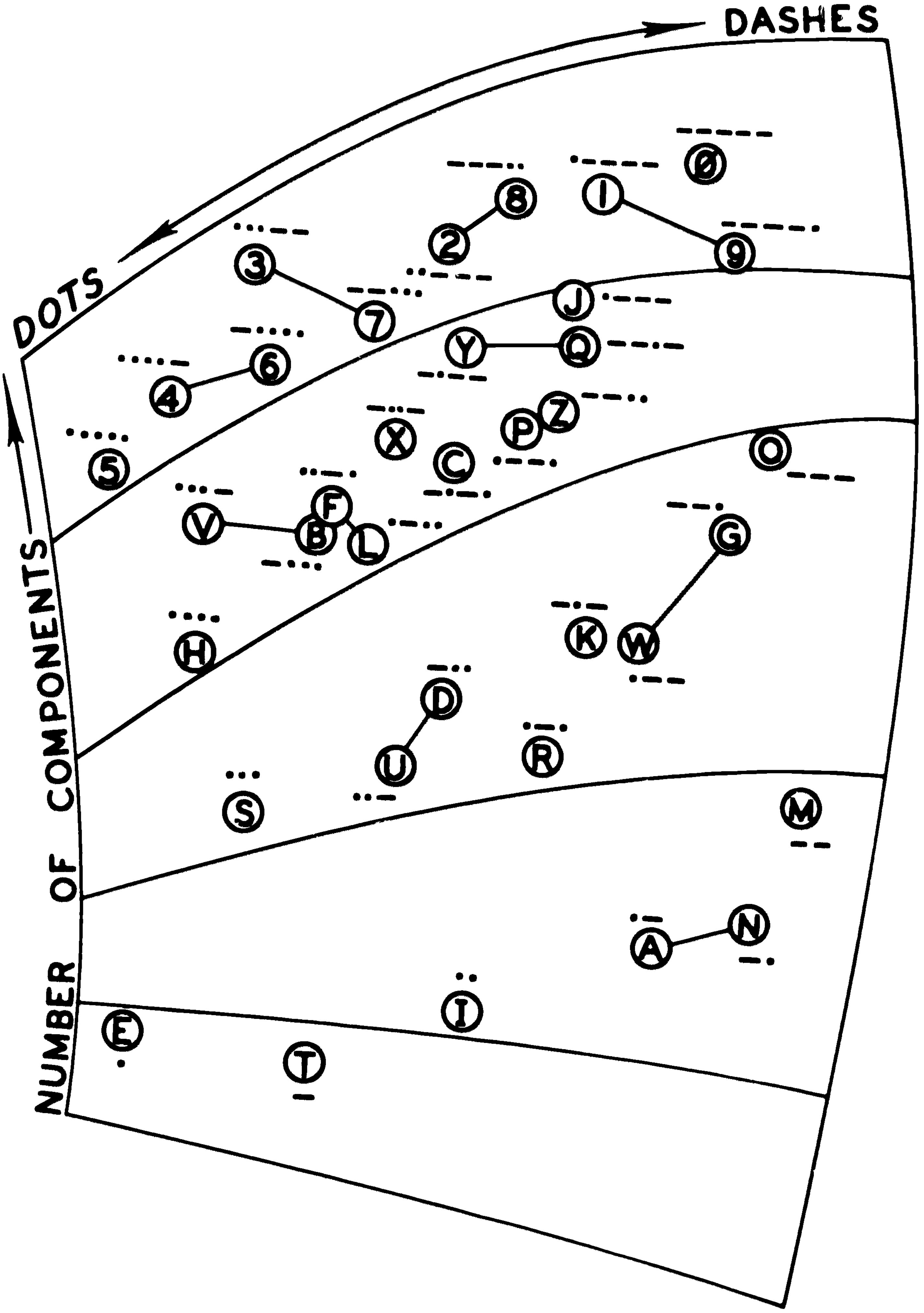


Fig. 1. A two-dimensional configuration of all 36 International Morse Code signals based upon the same-or-different judgments obtained by Rothkopf - I. [Kruskal symmetric solution - from Shepard, 1963, p. 39]

of the original nonsymmetric matrix. Shepard (p. 39) describes his configuration as follows:

The Centers of the circles give the positions of the 36 points as specified by the 72 coordinates of the final solution. The curvilinear lines are not part of this solution per se; these lines were subsequently added to facilitate communication of the interpretation that I am inclined to place on the total configuration of points. The symbol inscribed in each circle is the one assigned to the corresponding dot-and-dash pattern in the Morse Code. The dot-and-dash pattern itself is indicated just outside the circle.

As you can see, I have used the lines to divide the roughly rectangular region of the solution into five more or less parallel strips or bands. All signals within any one band contain the same number of elementary components (i.e., dots and/or dashes). Moreover these five bands occur in order, with respect to their associated number of components from the bottom band, which contains the two one-component signals, to the top band, which contains the ten five-component signals. Clearly then, the axis that cuts across these five bands in this two-dimensional configuration defines a dimension of number of components....

The interpretation of the second dimension seems equally clear. If we examine the disposition of signals within any one band, we immediately see that dots predominate on the left and dashes on the right. Moreover, the ratio between the numbers of these two types of components steadily shifts in the same direction as we traverse the length of any one band.

Let us examine Fig. 1 carefully to see if we can observe any other patterns in this configuration. In the description of the most

common kinds of errors made by Ss, it was pointed out that signals are more likely to be confused if they differ on the last component than if they differ on any other component. We should, therefore, expect signals that differ on the last component to be closer to each other than signals that differ on any other component. Figure 1 shows that this is generally true.

The configuration appearing in Fig. 2 is the same as that shown in Fig. 1. The only difference in the figures is in terms of the boundary lines. With few exceptions if $x < y$, then y is above x in Figs. 1 and 2. More generally, signals having the same temporal length are in the same band; straight line boundaries separate signals having different temporal lengths; and the bands are ordered according to temporal length. Signals that fall between an adjacent pair of diagonal lines generally have the same number of components. There are a few violations of these patterns, however.

The signals within each region determined by the intersections of the horizontal and diagonal lines have the same number of components and temporal length; therefore, they have the same combination of dots and dashes. One can observe that sets of signals whose corresponding submatrices are predicted to be simplexes (as those displayed in Table 4) fall along arcs going from the lower left-hand corner to the upper right-hand corner of the figure.

Now let us look at Figs. 3 and 4. Although these configurations are structurally very similar to the configurations we have discussed, they were obtained by nonsymmetric, rather than symmetric procedures. By suitable rotations (which do not alter the configuration) the similarity of these configurations becomes even more apparent. As described below the figures, the configuration of Fig. 3 is the solution

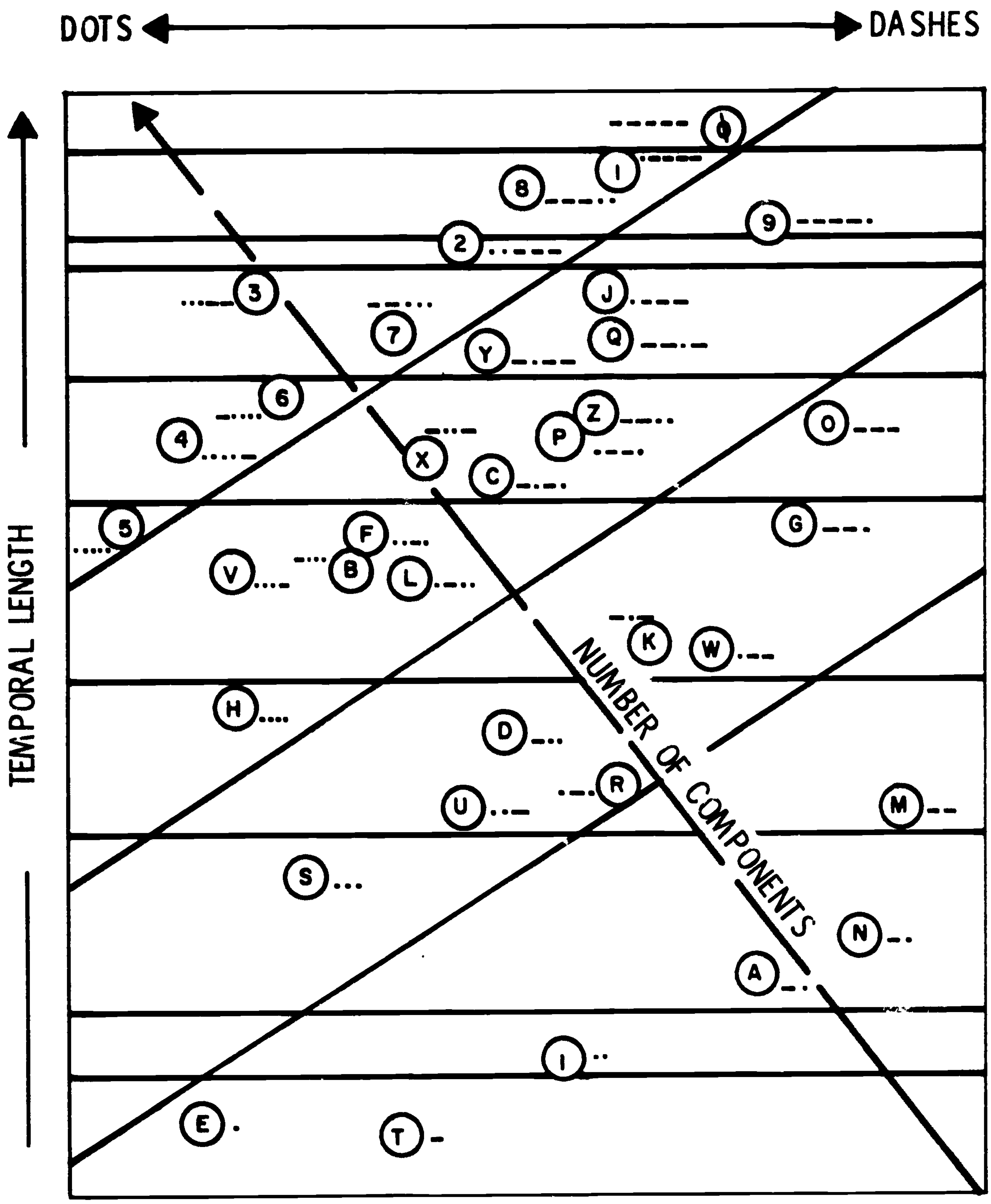


Fig. 2. A two-dimensional configuration of all International Morse Code signals based upon the same-or-different judgments obtained by Rothkopf - II. [Kruskal symmetric solution - from Shepard, 1963, p. 39]

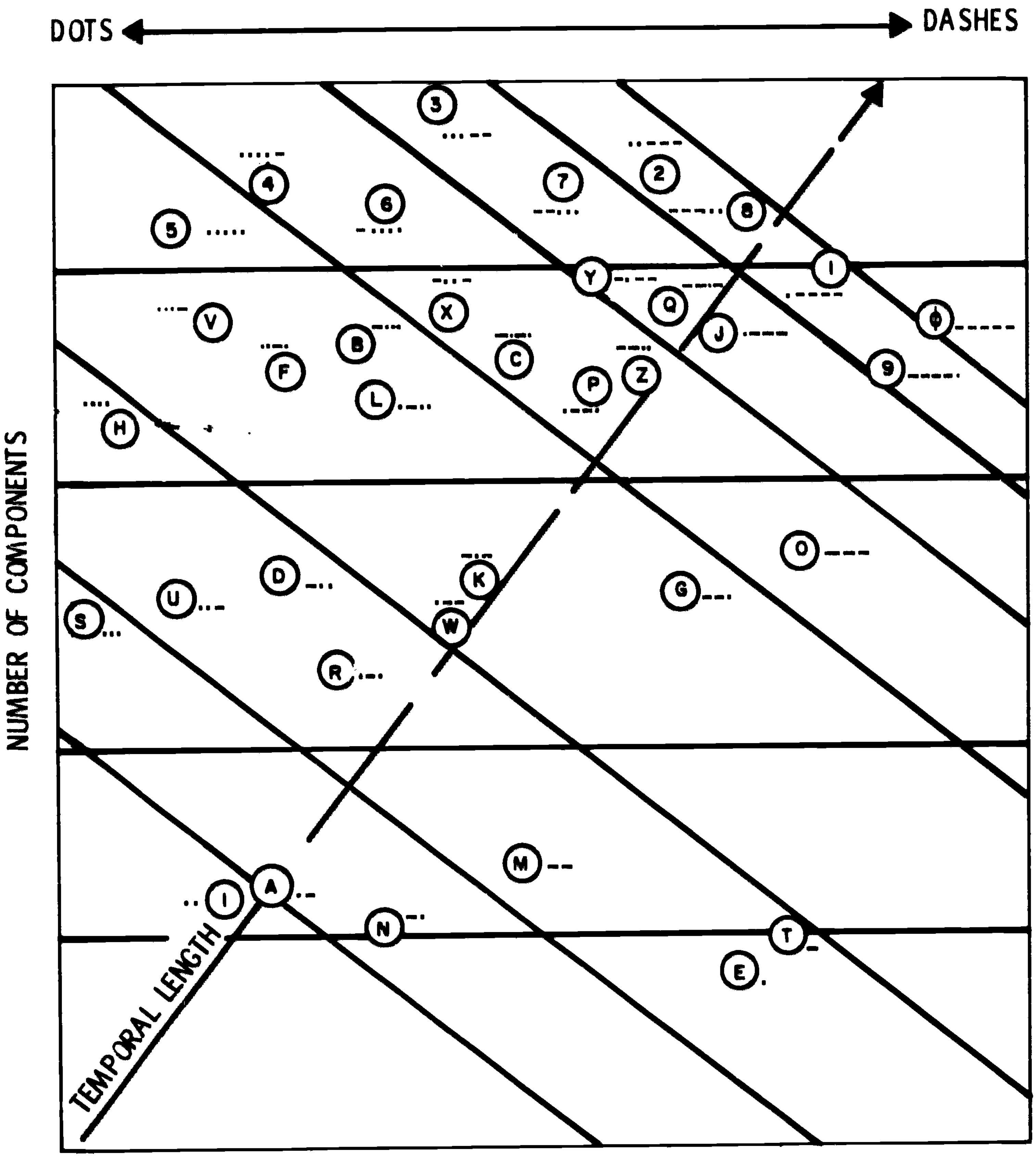


Fig. 3. A two-dimensional configuration of all International Morse Code signals based upon the same-or-different judgments obtained by Rothkopf - III. [Kruskal non-symmetric solution]

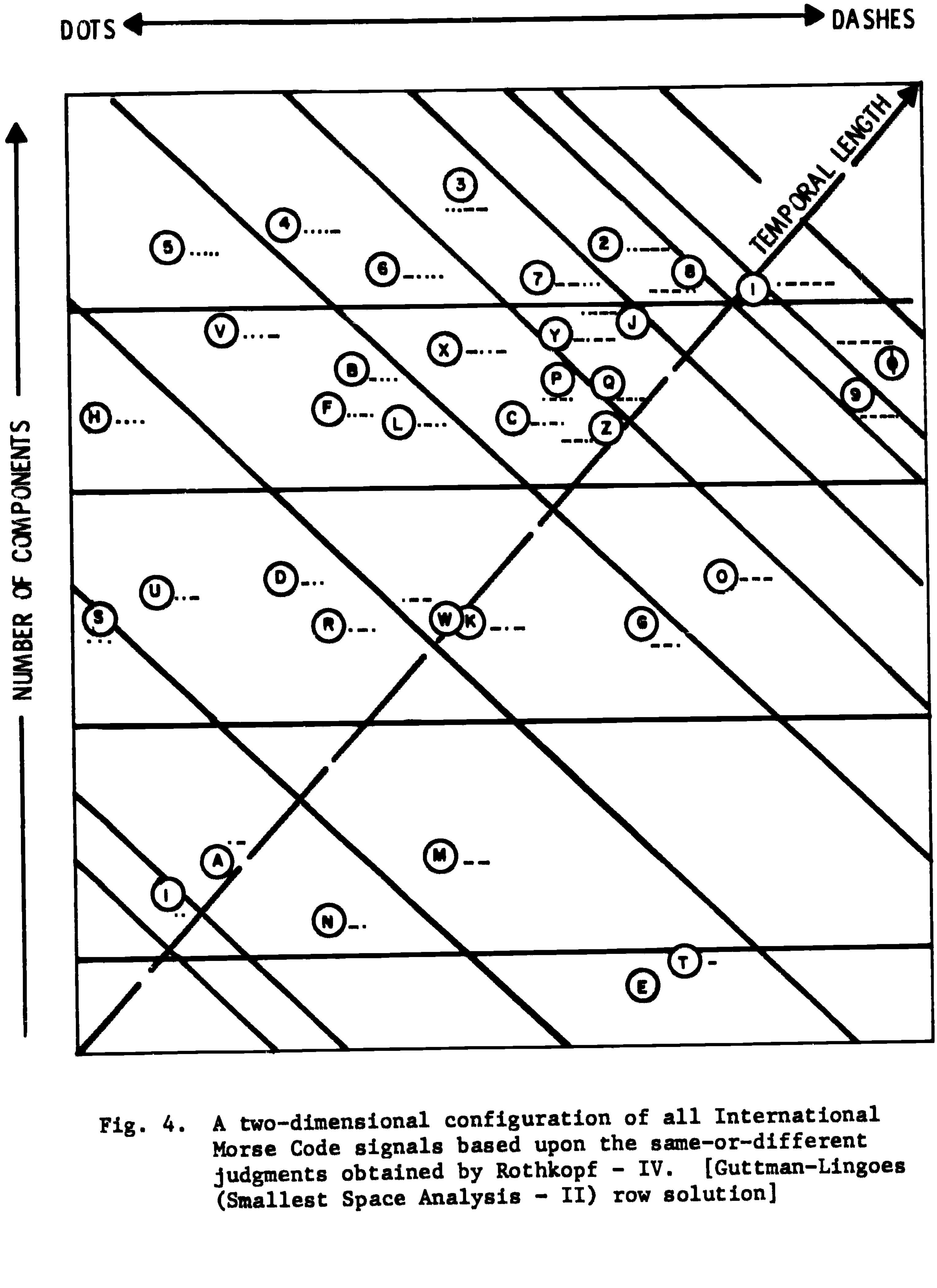


Fig. 4. A two-dimensional configuration of all International Morse Code signals based upon the same-or-different judgments obtained by Rothkopf - IV. [Guttman-Lingoes (Smallest Space Analysis - II) row solution]

(stress = .23) obtained by applying the Kruskal procedure with the nonsymmetric option, whereas the configuration of Fig. 4 is the row solution (coefficient of alientation = .18) obtained by means of G-L(SSA-II) of Guttman and Lingoes (Lingoes, 1965b). In the Kruskal procedure (symmetric or nonsymmetric option) a solution is sought which will best satisfy all inequalities of the form $D_{i,j} \leq D_{k,l}$ (where $D_{i,j}$ is the distance between points i and j in the configuration) if and only if $p(i,j) \geq p(k,l)$. Thus all cells in the matrix are assumed to be comparable. In the Guttman-Lingoes row solution only cells within the same row are assumed to be comparable. Thus one attempts only to satisfy inequalities of the form $D_{i,j} \leq D_{i,k}$ if and only if $p(i,j) \geq p(i,k)$. In the Guttman-Lingoes column solution one attempts to satisfy all inequalities of the form $D_{j,i} \leq D_{k,i}$ if and only if $p(j,i) \geq p(k,i)$. The rationale for using G-L(SSA-II) is that there is a systematic nonsymmetry in the matrix In order for the Kruskal procedure to be entirely legitimate, the departure from symmetry should be due to statistical fluctuation (Kruskal, 1964a; p. 21). For a further discussion concerning the differences between the Guttman-Lingoes and Kruskal procedures, see Lingoes (1966b, in press).

Figure 5 shows the first two dimensions of the 3-dimensional G-L(SSA-II) row solution (coefficient of alienation = .13). This figure is quite similar to the other figures. The third dimension of this configuration is provided in Table 7. Observe that the signals of a given temporal length that begin with a dash are always higher on the third dimension than those of that temporal length that begin with a dot. Furthermore, if the first dash of one signal occurs on an earlier component than the first dash of another signal which has the same temporal length, then the first signal is higher than the

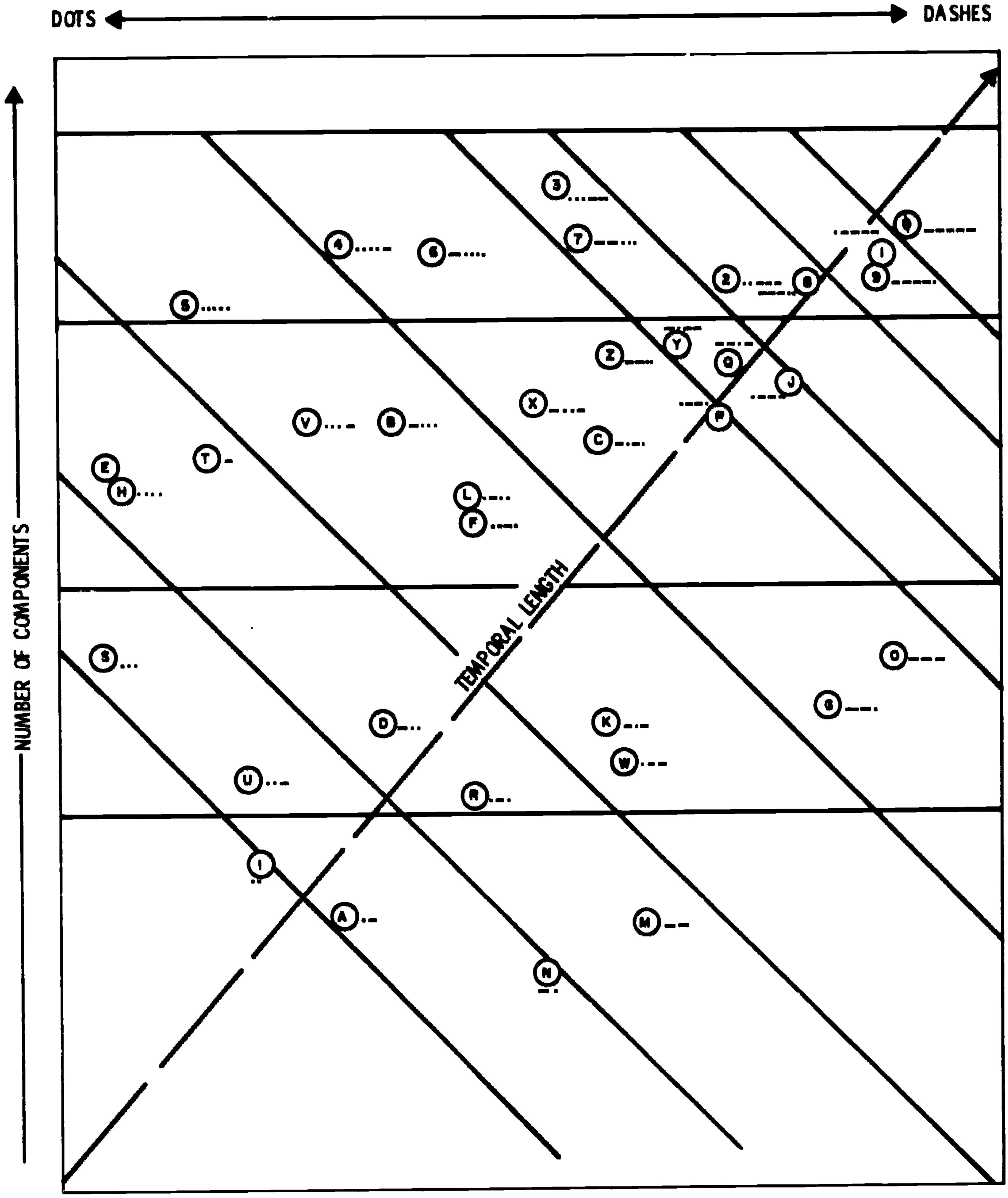


Fig. 5. First two dimensions of a three-dimensional analysis of Rothkopf's data. [Guttman-Lingoes (Smallest Space Analysis - II) row solution]

TABLE 7

Third Dimension of the Three-Dimensional G-L(SSA-II) Row Solution

Signal	Temporal Length in Units	Projection on Third Dimension	Signal	Temporal Length in Units	Projection on Third Dimension
•	1	1350	— — • •	11	185
			— • • • •	11	120
—	3	1510	— — —	11	-120
• •	3	750	— • — •	11	-120
			— • • —	11	-360
— •	5	725	• — — •	11	-505
• —	5	510	• • • • —	11	-580
• • •	5	0			
			— — • • •	13	75
— —	7	665	— — • —	13	-115
— • •	7	-325	— • — —	13	-280
• — •	7	-400	• • • • —	13	-420
• • —	7	-430	• • • — —	13	-630
• • • •	7	-450			
			— — — • •	15	185
— • • •	9	-110	• • — — —	15	-375
— — •	9	-140			
— • —	9	-250	— — — — •	17	570
• — • •	9	-365	• — — — —	17	-240
• • • • •	9	-525			
• — —	9	-775	— — — — —	19	540
• • — •	9	-820			
• • • —	9	-840			

second signal on the third dimension. Thus the third dimension groups signals of a given temporal length on the basis of the particular sequence in which the components occur.

By means of these multidimensional configurations we can comprehend the basic pattern of interrelations latent in Rothkopf's data matrix. We can observe that the temporal length, the number of components, the relative number of dashes, and the precise sequences of dots and dashes in these signals are all relevant to the perceptual-judgmental process. As a step toward developing a more general theory for pattern perception, a model for another signal universe will be proposed. In the next chapter I shall describe explicitly the signal universe of the second model, propose some hypotheses about the relative confusability of these signals, and test these hypotheses.

CHAPTER 3. THE SECOND MODEL

I. The Universe of Content

The signals studied in this model are identical with the 3-component International Morse Code signals in terms of the combinations of dots and dashes. However, whereas in the IMC signals (as well as in all other signals in μ_1) the silent intervals between each pair of adjacent tones are always one unit in duration, in the signals of this model the silent intervals (like the tones) can be either one unit or three units in duration. The signals in this universe can be described as rhythmic patterns, since varying the silences affects the rhythm of the signals.

Formally, the signal universe for the second model, μ_2, is equal to $\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$, where Δ is a set whose elements are a 1-unit tone (a dot) and a 3-unit tone (a dash), and Σ is a set whose elements are a 1-unit silence (a short silence) and a 3-unit silence (a long silence). Since Δ and Σ have two elements each, $\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$ has $2^5 = 32$ elements. Eight of these elements, (the signals having two short silences, i.e., silent intervals) are also in the International Morse Code. Thus $\mu_1 \cap \mu_2 =$ {(...), (..-), (.-.), (-..), (.--), (-.-), (--.), (---)}.

Because the silent intervals in the signals of μ_1, were always one unit long, there was no need to indicate explicitly the duration of each intercomponent silent interval. In these Morse-like rhythmic patterns, however, a <u>1</u> or a <u>3</u> will be written between a pair of tones in order to indicate whether there is one or three units of silence, respectively, between these tones. For example, in (.1.3-) the first silence is 1-unit in duration, while the second is three units in duration. This signal differs from the IMC signal (..-), which will be represented here as (.1.1-), only in terms of the duration of the second silence.

In Table 8 the signals in μ_2 are listed along with a set of alphabetic equivalents, each of which has a subscript. All signals with the same dot-and dash, or tonal, pattern have been assigned the same letter, the letter corresponding to that pattern in the International Morse Code. All signals with the same pattern of silent intervals have been assigned the same subscript. The signals whose alphabetic equivalents have 1's as subscripts are the eight 3-component signals of the International Morse Code.

In discussing the signals of this model it will be convenient to refer to the silences, as well as the dots and dashes, as being components of the signals. Each signal, then, has five components; the first, third, and fifth components are tones, whereas the second and fourth components are silences.

II. The Structural Hypotheses

Although the hypotheses of this model are quite similar to those of the first model, it will be necessary to modify some of the previous definitions and to define some additional terms.

A. The First Hypothesis

Definition 1.

For all, x, y ε μ_2, <u>x < y</u> iff the duration of each component of x is less than or equal to the duration of the corresponding component of y, and the duration of at least one component of x is less than the duration of the corresponding component of y, i.e., iff x is <u>weakly dominated</u> by y.

For example, (.1.1.) < (.1.3.) < (.1-3.) < (-1-3.) < (-3-3.) < (-3-3-). On the other hand (.1.3-) and (-1-3.) are not comparable--neither (.1.3-) < (-1-3.) nor (-1-3.) < (.1.3-)--since each signal exceeds the other on some component. One can observe that the ordering among the eight

TABLE 8

The Signal Universe for Model 2

Signal	Alphabetic Equivalent	Temporal Length in Units	Signal	Alphabetic Equivalent	Temporal Length in Units
• | • | •	S_1	5	• | - | -	W_1	9
• | • 3 •	S_2	7	• | - 3 -	W_2	11
• 3 • | •	S_3	7	• 3 - | -	W_3	11
• 3 • 3 •	S_4	9	• 3 - 3 -	W_4	13
• | • | -	U_1	7	- | • | -	K_1	9
• | • 3 -	U_2	9	- | • 3 -	K_2	11
• 3 • | -	U_3	9	- 3 • | -	K_3	11
• 3 • 3 -	U_4	11	- 3 • 3 -	K_4	13
• | - | •	R_1	7	- | - | •	G_1	9
• | - 3 •	R_2	9	- | - 3 •	G_2	11
• 3 - | •	R_3	9	- 3 - | •	G_3	11
• 3 - 3 •	R_4	11	- 3 - 3 •	G_4	13
- | • | •	D_1	7	- | - | -	O_1	11
- | • 3 •	D_2	9	- | - 3 -	O_2	13
- 3 • | •	D_3	9	- 3 - | -	O_3	13
- 3 • 3 •	D_4	11	- 3 - 3 -	O_4	15

signals of the IMC determined by this definition is identical to the ordering obtained for these signals in the first model.

Definition 2.

For all x, y ε μ_2, y is an immediate successor of x iff $x < y$, and there is no $z \varepsilon \mu_2$ such that $x < z < y$.

It follows from this definition that y is a successor of x iff x can be transformed to y by changing one of x's dots to a dash or by changing one of x's short silences to a long silence.

Definition 3.

For all x, y, z ε μ_2, y is immediately bounded by x and z iff one of the following is true:

(1) y is an immediate successor of x, and z is an immediate successor of y; or

(2) y is an immediate successor of z, and x is an immediate successor of y.

Thus since (-1-3.) is an immediate successor of (.1-3.) and (-3-3.) is an immediate successor of (-1-3.), (-1-3.) is immediately bounded by (.1-3.) and (-3-3.), or equivalently, (-1-3.) is immediately bounded by (-3-3.) and (.1-3.).

Definition 4.

For all x, y, z ε μ_2, x is closer to y than to z in the ordering on μ_2 iff $x < y < z$ or $z < y < x$.

Hypothesis 1.

For all x, y, z ε μ_2, if x is closer to y than to z in the ordering on μ_2, then x will be confused more often with y than with z.

B. The Second Hypothesis

Before stating the second hypothesis, I shall define four kinds of betweenness for signals, all of which are concerned with temporal

properties of the signals. In these definitions d(x), s(x), and t(x) denote the number of dashes in x, the number of long silences in x, and the temporal length of x, respectively.

Definition 5.

For all x, y, z ε μ_2, y is component-wise between x and z iff for all i, the i^{th} component of y is the same as the i^{th} component of x and/or the i^{th} component of z.

Definition 6.

For all x, y, z ε μ_2, y is dash-wise between x and z iff either $d(x) \leq d(y) \leq d(z)$ or $d(z) \leq d(y) \leq d(x)$.

Definition 7.

For all x, y, z ε μ_2, y is silence-wise between x and z iff either $s(x) \leq s(y) \leq s(z)$ or $s(z) \leq s(y) \leq s(x)$.

Definition 8.

For all x, y, z ε μ_2, y is time-wise between x and z iff either $t(x) \leq t(y) \leq t(z)$ or $t(z) \leq t(y) \leq t(x)$.

If y equals x or z, or if x is closer to y than to z in the ordering on μ_2, then y is component-wise, dash-wise, silence-wise, and time-wise between x and z. However, it is not necessary for y to be equal to x or z, or for x to be closer to y than to z in the ordering on μ_2 for y to be between x and z in all four senses. Some examples are as follows:

1. Let x = (.3.3.), y = (-3.1.), and z = (-1.1-).
2. Let x = (-1-3.), y = (.1-3-), and z = (.1.3-).
3. Let x = (.1.3-), y = (.3.1-), and z = (.3-1-).

In all three examples y is component-wise, dash-wise, silence-wise and time-wise between x and z. However, in each of these examples x, y, and z are distinct and x is not closer to y than to z in the ordering on

μ_2. It is important to note that it is possible for y to be between x and z in any three of these ways without being between x and z in the remaining way. These examples illustrate this point.

1. Let x = (-1.1.), y = (-3.1.), and z = (-1.3.).

Although y is dash-wise, silence-wise, and time-wise between x and z, y is not component-wise between x and z -- the second component of y differs from the second component of both x and z.

2. Let x = (.1-3.), y = (.3.3.) and z = (-3.3.).

Although y is component-wise, silence-wise, and time-wise between x and z, y is not dash-wise between x and z. Observe that y has fewer dashes than both x and z.

3. Let x = (.1-3-), y = (-3.3.), and z = (-3.1.).

The only sense in which y is not between x and z is silence-wise betweenness--the number of long silences in y is greater than the number of long silences in both x and z. Observe that y is component-wise, dash-wise, and time-wise between x and z.

4. Let x = (-1-1-), y = (.1-1-), and z = (.3.3-).

Although y is component-wise, dash-wise, and silence-wise between x and z, y is not time-wise between x and z -- the temporal length of y is 9 units, whereas the temporal length of both x and z is 11 units.

Hypothesis 2.

For all x, y, z ε μ_2, ($x \neq y \neq z$), if

(i) y is component-wise between x and z,

(ii) y is dash-wise between x and z,

(iii) y is silence-wise between x and z,

(iv) y is time-wise between x and z, and in addition

(v) neither $x < y < z$ nor $z < y < x$,

then x will be confused more often with y than with z.

For example, it is predicted that:

1. (.3.3.) will be confused more often with (-3.1.) than with (-1.1-), and that (-1.1-) will be confused more often with (-3.1.) than with (.3.3.);

2. (-1-3.) will be confused more often with (.1-3-) than with (.1.3-), and that (.1.3-) will be confused more often with (.1-3-) than with (-1-3.); and

3. (.1.3-) will be confused more often with (.3.1-) than with (.3-1-), and that (.3-1-) will be confused more often with (.3.1-) than with (.1.3-).

Having stated the hypotheses, I shall now describe an experiment which was designed expressly for testing the second model.

III. A Test of the Second Model

A. Experimental Design

Three-hundred-twenty-four Ss, all of whom were female undergraduates at the University of Michigan enrolled in an introductory psychology course,[3] participated without pay in the experiment. None of the Ss had had any prior training in Morse Code. The Ss, who were run in nine groups of 36 Ss each, were presented ordered pairs of the Morse-like rhythmic patterns and were asked to indicate on an IBM True-False Answer Sheet whether they thought that the two signals of each pair were the same or different. Six groups of Ss responded to 363 signal pairs; the remaining three groups responded to 362 pairs.

[3]The only reason for using all female Ss was that there were no male Ss available in the S pool.

Six lists of 363 signal pairs each and three lists of 362 signal pairs each were used in the experiment. The lists were constructed as follows. In 992 of the $32^2 = 1024$ possible ordered pairs of signals, the first and second signals of the pair are different. These 992 pairs were divided randomly into two groups of 331 pairs each and one group of 330 pairs. Adding the 32 remaining pairs--the pairs in which the first and second signal were identical--to each of these groups brought the total number of signal pairs in two groups, Groups I and II, to 363 and the total number of pairs in Group III to 362. Each of these groups was further trichotomized into an A, B, and a C subset. Subsets IA, IB, IIA, IIB, IIIA, and IIIB each contained 120 pairs, subsets IC and IIC contained 123 pairs each, and subset IIIC contained 122 pairs. The order of presentation for pairs within each subset was determined by a random number table.

With these nine subsets nine lists were then constructed according to the design shown in Table 9. In list 1, the pairs of subset IA are presented first, followed by the pairs of subset IB, and terminated with the pairs of subset IC. Although the same signal pairs appear in the first three lists, the order in which the subsets occur in the lists differs. The order of presentation of pairs within a subset, however, is the same in all lists in which that subset appears.

Each group of Ss responded to one of these nine lists. Since each subset appeared first in one list, second in another list, and third in still another list, each subset (and therefore each of the 992 pairs in which the first and second signals differ) was presented to one group of Ss during the first third of its experimental session, to another group during the middle third of its experimental session, and to still another group during the final third of its session. Because the 32

TABLE 9

The Nine Lists Used in the Experiment

List	First Subset Presented	Second Subset Presented	Third Subset Presented
1	IA	IB	IC
2	IB	IC	IA
3	IC	IA	IB
4	IIA	IIB	IIC
5	IIB	IIC	IIA
6	IIC	IIA	IIB
7	IIIA	IIIB	IIIC
8	IIIB	IIIC	IIIA
9	IIIC	IIIA	IIIB

"identical" pairs appeared in stimulus groups I, II, and III, the "identical" pairs were actually presented to three groups of Ss in each third of the experiment. For example, the pairs in subset IIB were presented to group 5 during the first third, to group 4 during the second third, and to group 6 during the final third of the session. Since every pair was presented during each third of the experiment, it was possible to investigate systematic changes in the patterns of confusion over the course of the experiment.

The nine lists were read as input into a PDP-4 digital computer (manufactured by the Digital Equipment Corporation). The computer then generated the signal pairs in the order specified for each list. The output for each list was recorded from the computer through external analog equipment onto magnetic tape. A temporal unit of .03 sec. was utilized instead of the .05 sec. unit used by Rothkopf, since at the .05 sec. per unit rate Ss confused nonidentical signals only 5% of the time. Since the temporal unit was .03 sec., the duration of dots and 1-unit silences was .03 sec. whereas the duration of dashes and 3-unit silences was .09 sec. As in Rothkopf's experiment, the silent period between the signals of a pair was 1.4 sec. and the interval between pairs was 3.0 sec. A 4.6 sec. silent period was interposed after every 15 pairs during which time Ss were told the item number of the pair which would be presented next. In addition after every 120 pairs Ss were given a one-minute rest.

Preceding the stimuli on each tape were the instructions which appear in the Appendix. The tapes were played on an Ampex 6022 field recorder and were amplified by an Ampex 620 amplifier-speaker system. The speaker was placed on the floor in the front of a 60' x 25' room. The Ss sat in six rows of six Ss each facing the speaker.

The distance from the speaker to the Ss ranged from 12 to 30 feet. The volume was adjusted so as to make the stimuli clearly audible to all Ss, but the sound pressure level was not measured. The total time for each experimental session was 45 minutes—8 minutes for the instructions and practice trials, 32 minutes for stimulus presentation, and 5 minutes for a postexperimental questionnaire.

B. A Restatement of the Hypotheses

As in Rothkopf's experiment, $p(x,y)$ denotes the percentage of "same" responses to the ordered pair (x,y). The hypotheses of the second model will now be stated in terms of these percentages.

Hypothesis 1.

For all $x, y, z \in \mu_2$, if x is closer to y than to z in the ordering on μ_2, then $p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

Hypothesis 2.

For all $x, y, z \in \mu_2$, $(x \neq y \neq z)$, if

(i) y is component-wise between x and z,

(ii) y is dash-wise between x and z,

(iii) y is silence-wise between x and z,

(iv) y is time-wise between x and z, and in addition,

(v) neither $x < y < z$ nor $z < y < x$,

then $p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

Since the same fundamental considerations motivate both the first and second models, the test of these hypotheses will also test the generality of this facet-theoretic type of approach.

C. Simplexes and Double Simplexes in the Data Matrix

The data from the total experiment, as well as the data obtained during each third of the experiment, can be summarized in a 32 x 32 matrix whose rows indicate the signal presented first, whose columns indicate the signal presented second, and whose cells indicate the percentage of "same" responses to the corresponding ordered pairs. (These matrices will be shown in the next section of this chapter.) We should again expect each cell on the main diagonal to be greater than any other cell in its row and column, since the diagonal cells indicate the percentage of "same" responses to pairs of identical signals. Some consequences of the hypotheses of the second model for the structure of certain submatrices of the 32 x 32 data matrix are as follows:

(1) If $w < x < y < z < < <$, then the submatrix whose rows and columns are ordered w, x, y, z,....should be a simplex.

For example, since (.1.1.) < (.1.3.) < (.1-3.) < (-1-3.) < (-3-3.) < (-3-3-) -- $S_1 < S_2 < R_2 < G_2 < G_4 < O_4$ --, it is predicted that the submatrix whose rows and columns are ordered S_1, S_2, R_2, G_2, G_4, O_4 will be a simplex.

(2) If (i) $w < x < y < z$ and $w' < x' < y' < z'$,

(ii) w, x, y, and z have the same number of dashes and the same number of long silences as w', x', y', and z', respectively, and

(iii) w, x, y, and z differ from w', x', y', and z', respectively, on exactly the same components,

then the submatrix whose rows and columns are ordered w, x, y, z, w', x', y', z' should be a double simplex.

Example:

Let w = (-1.1.), x = (-1.1-), y = (-1.3-), z = (-3.3-),

w' = (.1-1.), x' = (.1-1-), y' = (.1-3-) and z' = (.3-3-).

Since (i) $w < x < y < z$ and $w' < x' < y' < z'$,

(ii) d(w) = d(w') and s(w) = w(w'),

d(x) = d(x') and s(x) = s(x'),

d(y) = d(y') and s(y) = s(y'),

d(z) = d(z') and s(z) = s(z'), and

(iii) w, x, y, and z differ from w', x', y', and z', respectively, only on the first and third components,

it is predicted that the submatrix whose rows and columns are ordered (-1.1.), (-1.1-), (-1.3-), (-3.3-), (.1-1.), (.1-1-), (.1-3-), (.3-3-) -- D_1, K_1, K_2, K_4, R_1, W_1, W_2, W_4 -- will be a double simplex.

IV. Results and Discussion

A. The Hypotheses

The percentage of "same" responses to each ordered pair in the total experiment is given in Tables 10, 11, and 12. These three permutations have been provided in order to make it easier to comprehend the patterns of confusion among the signals. As before, the rows indicate the signal presented first, and the columns indicate the signal presented second.

The mean percentage of "same" judgments for the pairs associated with the diagonal cells, 95.4%, is greater than the corresponding mean in Rothkopf's data, 89.3%. The same holds true for the pairs associated with the off-diagonal cells; the mean percentage of "same" responses to

Table 10 Percentage of "same" judgments obtained for all ordered pairs of the 32 Morse-like rhythmic patterns. Signals grouped according to dot-and-dash pattern.

	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	
·I·I·S_1	97	79	44	02	94	18	11	02	81	28	05	00	66	11	01	00	16	01	00	00	31	04	02	01	06	02	01	03	03	01	02	02	S_1
·I·3·S_2	44	94	69	25	54	84	45	11	62	62	27	03	56	54	39	17	32	38	10	00	41	22	21	00	19	07	06	02	04	00	01	02	S_2
·3·I·S_3	42	69	94	47	38	53	91	13	30	31	59	12	48	33	54	27	23	30	16	02	22	03	45	03	19	05	03	02	06	01	05	00	S_3
·3·3·S_4	02	28	44	96	05	17	55	78	04	15	57	59	02	28	19	47	06	07	28	06	05	07	12	35	06	23	19	36	12	08	15	03	S_4
·I·I–U_1	63	57	44	03	98	61	35	00	86	49	06	03	74	21	08	03	91	13	04	05	73	00	07	01	23	06	03	00	16	00	01	02	U_1
·I·3–U_2	03	63	30	20	30	94	45	27	44	39	22	03	15	52	24	00	66	77	21	04	61	48	34	15	29	14	00	05	19	07	14	03	U_2
·3·I–U_3	04	30	56	17	09	29	94	34	30	14	53	19	18	21	57	15	42	30	64	10	52	22	67	16	35	05	23	02	29	05	12	03	U_3
·3·3–U_4	00	04	04	45	01	14	52	97	04	20	50	55	06	13	12	28	12	19	59	67	17	29	26	64	22	35	19	13	26	26	44	13	U_4
·I–I·R_1	27	42	23	07	73	52	22	07	94	64	23	12	30	49	22	09	72	30	14	01	62	11	12	05	31	16	12	02	22	00	04	00	R_1
·I–3·R_2	05	31	19	10	16	38	25	14	48	95	33	27	15	47	34	32	59	86	33	11	19	36	19	02	45	53	21	06	28	12	07	01	R_2
·3–I·R_3	05	10	29	27	05	17	53	37	43	40	94	65	08	31	52	27	22	28	84	19	24	31	43	30	38	24	62	11	20	05	55	03	R_3
·3–3·R_4	02	03	04	31	01	06	17	29	10	49	66	94	02	23	21	48	16	21	45	61	07	17	06	31	20	30	44	61	17	30	34	05	R_4
–I·I·D_1	47	43	28	03	75	13	16	02	69	40	17	00	96	34	50	07	33	11	00	03	94	26	05	02	67	19	03	04	00	02	06	00	D_1
–I·3·D_2	06	47	09	19	14	39	18	17	28	43	34	19	46	94	42	51	26	35	15	05	51	79	37	34	60	73	33	08	43	35	16	00	D_2
–3·I·D_3	01	19	30	06	04	36	36	05	06	21	35	07	26	51	94	60	00	06	16	01	47	19	97	15	31	21	47	05	05	04	20	01	D_3
–3·3·D_4	01	01	03	26	03	05	25	42	07	07	16	30	06	28	67	97	13	06	25	31	05	19	52	03	28	22	78	60	33	25	67	03	D_4
·I–I–W_1	03	20	22	09	40	51	33	19	64	73	25	19	42	40	17	11	94	69	31	06	76	49	10	00	68	54	12	06	70	31	08	00	W_1
·I–3–W_2	02	07	05	04	14	54	21	22	24	69	19	06	09	31	19	13	62	94	44	14	39	64	29	19	27	36	19	03	39	41	34	11	W_2
·3–I–W_3	01	04	14	15	02	16	51	60	15	21	72	41	02	08	19	44	32	36	94	51	12	29	31	49	37	53	56	29	50	34	76	31	W_3
·3–3–W_4	00	01	03	25	02	03	05	46	03	14	19	55	02	06	08	50	06	38	56	93	06	09	12	59	22	42	38	65	33	54	60	74	W_4
–I·I–K_1	07	19	08	03	44	37	27	06	33	40	32	05	69	56	47	16	69	26	17	06	95	74	46	06	70	27	11	01	67	16	08	01	K_1
–I·3–X_2	01	14	03	01	03	19	18	06	05	23	14	06	07	68	25	31	22	40	14	15	54	98	33	37	37	47	41	10	56	72	37	07	K_2
–3·I–K_3	02	02	17	03	04	26	36	09	06	13	13	00	11	22	80	46	14	13	13	06	61	28	97	67	18	17	79	12	27	09	68	02	K_3
–3·3–K_4	01	01	04	06	01	05	08	42	00	02	06	15	02	10	28	81	02	11	15	16	07	27	75	98	05	28	56	37	32	34	83	53	K_4
–I–I· G_1	01	08	04	10	08	14	11	18	49	48	47	19	50	80	37	38	78	23	40	13	78	53	27	14	93	90	22	11	82	33	38	06	G_1
–I–3· G_2	01	08	01	05	75	07	10	11	10	46	27	32	08	57	08	54	30	44	36	21	28	42	23	44	71	93	59	57	73	71	50	19	G_2
–3–I· G_3	01	01	05	04	57	05	11	12	03	04	56	22	05	27	68	60	07	13	58	21	29	16	57	45	43	37	96	52	14	42	89	17	G_3
–3–3· G_4	01	02	00	05	01	03	03	22	01	07	11	35	01	01	07	62	06	08	27	33	06	11	08	55	26	50	74	97	18	47	80	51	G_4
–I–I– O_1	02	00	05	11	10	04	11	31	19	12	25	08	04	16	09	33	31	20	38	31	51	50	31	28	76	82	23	14	97	82	57	00	O_1
–I–3– O_2	00	00	02	02	01	04	06	15	04	07	07	11	03	24	03	31	21	55	19	47	08	58	14	41	35	58	25	51	80	94	60	56	O_2
–3–I– O_3	00	02	01	02	00	03	10	15	03	09	36	14	00	01	28	49	08	17	29	27	18	22	50	73	19	20	74	69	64	52	97	56	O_3
–3–3– O_4	00	02	03	06	02	01	01	09	00	00	00	17	01	02	01	05	00	06	06	42	01	05	03	53	07	35	26	75	09	64	89	97	O_4
	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	

Table 11 Percentage of "same" judgments obtained for all ordered pairs of the 32 Morse-like rhythmic patterns. Signals grouped according to silence patterns.

		S_1	U_1	R_1	D_1	W_1	K_1	G_1	O_1	S_2	U_2	R_2	D_2	W_2	K_2	G_2	O_2	S_3	U_3	R_3	D_3	W_3	K_3	G_3	O_3	S_4	U_4	R_4	D_4	W_4	K_4	G_4	O_4	
•1•1•	S_1	97	94	81	66	16	31	06	03	79	18	28	11	01	04	02	01	44	11	05	01	00	02	01	02	02	02	00	00	00	01	03	02	S_1
•1•1−	U_1	63	98	86	74	91	73	23	16	57	61	49	21	13	09	06	00	44	35	06	08	04	07	03	01	03	00	03	03	05	01	00	02	U_1
•1−1•	R_1	27	73	94	50	72	62	51	22	42	52	64	49	30	11	16	00	23	22	33	22	14	12	12	04	07	07	12	09	01	05	02	09	R_1
−1•1•	D_1	47	75	69	96	33	94	67	09	43	13	40	34	11	26	19	02	28	16	17	50	00	05	03	06	03	02	00	07	03	02	04	00	D_1
•1−1−	W_1	03	40	64	42	94	76	68	70	20	51	73	40	69	49	54	31	22	33	25	17	31	18	12	08	09	19	19	11	06	09	06	00	W_1
−1•1−	K_1	07	44	33	69	69	95	70	67	19	37	40	56	26	74	27	16	08	27	32	47	17	46	11	08	03	06	05	16	06	06	01	01	K_1
−1−1•	G_1	01	08	49	50	78	78	93	82	08	14	48	80	23	53	90	33	04	11	47	37	40	27	22	38	10	18	19	38	13	14	11	06	G_1
−1−1−	O_1	02	10	19	04	31	51	76	97	00	04	12	16	20	50	82	82	05	11	25	09	38	31	23	57	11	31	08	33	31	28	14	09	O_1
•1•3•	S_2	44	54	62	56	32	41	19	04	94	84	62	54	38	22	07	00	69	45	27	39	10	21	06	01	25	11	03	17	00	00	02	02	S_2
•1•3−	U_2	03	39	44	15	66	61	29	19	63	94	39	52	77	48	14	07	30	45	22	24	21	34	09	14	20	27	03	08	04	15	05	03	U_2
•1−3•	R_2	05	16	48	15	59	19	45	28	31	38	95	47	86	36	53	12	19	25	33	24	33	19	21	07	10	14	27	32	11	02	06	01	R_2
−1•3•	D_2	06	14	28	46	26	51	69	43	47	39	43	94	35	79	73	35	09	18	34	42	15	37	33	16	19	17	19	51	05	34	09	00	D_2
•1−3−	W_2	02	14	24	09	62	39	27	59	07	54	69	37	94	64	56	41	05	21	19	19	44	29	19	34	04	22	06	13	14	19	03	11	W_2
−1•3−	K_2	01	03	05	07	22	54	37	56	14	19	23	68	48	98	47	72	03	18	14	25	14	33	41	37	01	06	06	31	15	37	18	07	K_2
−1−3•	G_2	01	05	10	08	30	28	71	73	08	07	46	57	44	42	93	71	01	10	27	08	36	23	59	50	05	11	32	54	21	44	57	19	G_2
−1−3−	O_2	00	01	04	03	21	08	35	80	00	04	07	24	55	58	58	94	02	06	07	03	19	14	25	60	02	15	11	31	47	41	57	56	O_2
•3•1•	S_3	42	38	50	48	23	22	19	06	69	53	31	33	09	03	05	01	94	91	59	54	16	45	03	05	47	13	12	27	02	03	02	00	S_3
•3•1−	U_3	04	09	30	18	42	52	35	29	30	29	14	21	30	22	05	05	56	94	53	57	64	67	23	12	17	34	19	15	18	16	02	03	U_3
•3−1•	R_3	05	05	43	08	22	24	38	20	10	17	40	31	28	31	24	05	29	53	94	52	84	43	62	55	27	37	65	27	19	30	11	03	R_3
−3•1•	D_3	01	04	06	26	09	47	31	05	19	36	21	51	06	19	21	04	30	36	35	94	16	97	47	20	16	05	07	60	01	15	05	01	D_3
•3−1−	W_3	01	02	15	02	32	12	37	50	04	16	21	08	36	29	53	34	14	51	72	19	94	31	56	76	15	60	41	44	51	49	29	31	W_3
−3•1−	K_3	02	04	06	11	14	61	18	27	02	26	13	22	13	28	17	09	17	56	13	80	13	97	79	68	03	09	08	46	06	67	12	02	K_3
−3−1•	G_3	01	07	03	05	07	29	43	14	01	05	04	27	13	16	37	42	05	11	56	68	58	57	96	89	04	12	22	60	21	45	52	17	G_3
−3−1−	O_3	00	00	03	00	08	18	19	64	02	03	09	07	17	22	20	52	01	10	36	28	29	50	74	97	02	15	14	49	27	73	69	56	O_3
•3•3•	S_4	02	05	04	02	06	05	06	12	28	17	15	28	07	07	23	08	44	55	57	19	28	12	19	15	96	78	59	47	08	35	36	03	S_4
•3•3−	U_4	00	01	04	06	12	17	22	26	04	14	20	13	19	29	35	26	04	52	50	12	59	26	19	44	45	97	55	28	67	64	13	13	U_4
•3−3•	R_4	02	01	10	02	16	07	20	17	03	06	49	23	21	17	39	30	04	17	66	21	45	06	44	54	31	29	94	48	61	31	61	05	R_4
−3•3•	D_4	01	03	07	06	13	05	28	33	01	05	07	28	06	19	22	25	03	25	16	67	25	52	78	67	26	42	30	97	31	83	60	03	D_4
•3−3−	W_4	00	02	03	02	06	06	22	33	01	03	14	06	38	09	42	54	03	05	19	08	56	12	38	69	25	46	55	50	93	59	65	74	W_4
−3•3−	K_4	01	01	00	02	02	07	05	32	01	05	02	10	11	27	28	34	04	08	06	28	15	75	56	83	06	42	15	81	16	98	37	53	K_4
−3−3•	G_4	01	01	01	01	06	06	26	18	02	03	07	01	08	11	59	47	00	03	11	07	27	08	74	80	05	22	35	62	33	55	97	51	G_4
−3−3−	O_4	00	02	00	01	00	01	07	09	02	01	00	02	06	05	35	64	03	01	00	01	06	03	26	89	06	09	17	05	42	53	75	97	O_4
		S_1	U_1	R_1	D_1	W_1	K_1	G_1	O_1	S_2	U_2	R_2	D_2	W_2	K_2	G_2	O_2	S_3	U_3	R_3	D_3	W_3	K_3	G_3	O_3	S_4	U_4	R_4	D_4	W_4	K_4	G_4	O_4	

Table 12 Percentage of "Same" Judgments Obtained for All Ordered Pairs of the 32 Morse-like Rhythmic Patterns. Signals Grouped According to Temporal Length.

	S_1	S_3	S_2	U_1	R_1	D_1	S_4	U_3	R_3	D_3	U_2	R_2	D_2	W_1	K_1	G_1	U_4	R_4	D_4	W_3	K_3	G_3	W_2	K_2	G_2	O_1	W_4	K_4	G_4	O_3	O_2	O_4	
•|•|• S_1	97	44	79	94	81	66	02	11	05	01	18	28	11	16	31	06	02	00	00	00	02	01	01	04	02	03	00	01	03	02	01	02	S_1
•3•|• S_3	42	94	69	38	50	48	47	91	59	54	53	31	33	23	22	19	13	12	27	16	45	03	09	03	05	06	02	03	02	05	01	00	S_3
•|•3• S_2	44	69	94	54	62	56	25	45	27	39	84	62	54	32	41	19	11	03	17	10	21	06	38	22	07	04	00	00	02	01	00	02	S_2
•|•|- U_1	63	44	57	98	86	74	03	35	06	08	61	49	21	91	73	23	00	03	03	04	07	03	13	09	06	16	05	01	00	01	00	02	U_1
•|-|• R_1	27	[illegible]	42	73	94	50	07	22	33	22	52	64	49	72	62	51	07	12	09	14	12	12	30	11	16	22	01	05	02	04	00	09	R_1
-|•|• D_1	47	28	43	75	69	96	03	16	17	50	13	40	34	33	94	67	02	00	07	00	05	03	11	26	19	09	03	02	04	06	02	00	D_1
•3•3• S_4	02	44	28	05	04	02	96	55	57	19	17	15	28	06	05	06	78	59	47	28	12	19	07	07	23	12	08	35	36	15	08	03	S_4
•3•|- U_3	04	56	30	09	30	18	17	94	53	57	29	14	21	42	52	35	34	19	15	64	67	23	30	22	05	29	18	16	02	12	05	03	U_3
•3-|• R_3	05	29	10	05	43	08	27	53	94	52	17	40	31	22	24	38	37	65	27	84	43	62	28	31	24	20	19	30	11	55	05	03	R_3
-3•|• D_3	01	30	19	04	06	26	06	36	35	94	36	21	51	09	47	31	05	07	60	16	97	47	06	19	21	05	01	15	05	20	04	01	D_3
•|•3- U_2	03	30	63	39	44	15	20	45	22	24	94	39	52	66	61	29	26	03	08	21	34	09	77	48	14	19	04	15	05	14	07	03	U_2
•|-3• R_2	05	19	3	16	48	15	10	25	33	24	38	95	47	59	19	45	14	27	32	33	19	21	86	36	53	28	11	02	06	07	12	01	R_2
-|•3• D_2	06	09	47	14	28	46	19	18	34	42	39	43	94	26	51	69	17	19	51	15	37	33	35	79	73	43	05	34	09	16	35	00	D_2
•|-|- W_1	03	22	20	40	64	42	09	33	25	17	51	73	40	94	76	68	19	19	11	31	18	12	69	49	54	70	06	09	06	08	31	00	W_1
-|•|- K_1	07	08	19	44	33	69	03	27	32	47	37	40	56	69	95	70	06	05	16	17	46	11	26	74	27	67	06	06	01	08	16	01	K_1
-|-|• G_1	01	04	08	08	49	50	10	11	[illegible]	37	14	48	80	78	78	93	18	19	38	40	27	22	23	53	90	82	13	14	11	38	33	06	G_1
•3•3- U_4	00	04	04	01	04	06	45	52	50	12	14	20	13	12	17	22	97	55	28	59	26	19	19	29	35	26	67	64	13	44	26	13	U_4
•3-3• R_4	02	04	03	01	10	02	31	17	66	21	06	49	23	16	07	20	29	94	48	45	06	44	21	17	39	17	61	31	61	54	30	05	R_4
-3•3• D_4	01	03	01	03	07	06	26	25	16	67	05	07	28	13	05	28	42	30	97	25	52	78	06	19	22	33	31	83	60	67	25	03	D_4
3-|- W_3	01	14	04	02	15	02	15	51	72	19	16	21	08	32	12	37	60	41	44	94	31	56	36	29	53	50	51	49	29	76	34	31	W_3
-3•|- K_3	02	17	02	04	06	11	03	56	13	80	26	13	22	14	61	18	09	08	46	13	97	79	13	28	17	27	06	67	12	68	09	02	K_3
-3-|• G_3	01	05	01	07	03	05	04	11	56	68	05	04	27	07	29	43	12	22	60	58	57	96	13	16	37	14	21	45	52	89	42	17	G_3
•|-3- W_2	02	05	07	14	24	09	04	21	19	19	54	69	37	62	39	27	22	06	13	44	29	19	94	64	56	59	14	19	03	34	41	11	W_2
-|•3- K_2	01	03	14	03	05	07	01	18	14	25	19	23	68	22	54	37	06	06	31	14	33	41	48	98	47	56	15	37	18	37	72	07	K_2
-|-3• G_2	01	01	08	05	10	08	05	10	27	08	07	46	57	30	28	71	11	32	54	46	23	59	44	42	93	73	21	44	57	50	71	19	G_2
-|-|- O_1	02	05	00	10	19	04	11	11	25	09	04	12	16	31	[illegible]	76	31	08	33	38	31	23	20	50	82	97	31	28	14	57	82	09	O_1
•3-3- W_4	00	03	01	02	03	02	25	05	19	08	03	14	06	06	06	22	46	55	50	56	12	38	38	09	42	33	93	59	65	69	54	74	W_4
-3•3- K_4	01	04	01	01	00	02	06	08	06	28	05	02	10	02	07	05	42	15	81	15	75	56	11	27	28	32	16	98	37	83	34	53	K_4
-3-3• G_4	01	00	02	01	01	01	05	03	11	07	03	07	01	06	06	26	22	35	62	27	08	74	08	11	59	18	33	55	97	80	47	51	G_4
-3-|- O_3	00	01	02	00	03	00	02	10	36	28	03	09	07	08	18	19	15	14	49	29	50	74	17	22	20	64	27	73	69	97	52	56	O_3
-|-3- O_2	00	02	00	01	04	03	02	06	07	03	04	07	24	21	08	35	15	11	31	19	14	25	55	58	58	80	47	41	51	60	94	56	O_2
-3-3- O_4	00	03	02	02	00	01	06	01	00	01	01	00	02	00	01	07	09	17	05	06	03	26	06	05	35	09	42	53	75	89	64	97	O_4
	S_1	S_3	S_2	U_1	R_1	D_1	S_4	U_3	R_3	D_3	U_2	R_2	D_2	W_1	K_1	G_1	U_4	R_4	D_4	W_3	K_3	G_3	W_2	K_2	G_2	O_1	W_4	K_4	G_4	O_3	O_2	O_4	

the objectively different pairs is 26% in the current data, whereas it is only 17.6% in the Morse Code data. The difference in the confusion rates for the two experiments is probably a function of the difference in the populations, the difference in the signals, and the difference in the speeds at which the signals were presented. Since we have predicted only the relative magnitude of the percentages, the overall difference in confusion rate does not directly affect the hypotheses.

One can observe in either Table 10, 11, or 12 that in only two instances is a diagonal cell equalled or exceeded by another cell in its row or column--$p(D_3, D_3) < p(D_3, K_3)$, and $p(K_3, K_3) = p(D_3, K_3)$.

As before, the predictions following from the first hypothesis will be divided into two classes. In the first class are those predictions in which y is immediately bounded by x and z. Of the 1280 predictions in this class, 1262 (99%) are correct. The predictions in which y is not immediately bounded by x and z are in the second class. Of the 3120 predictions in the second class, 2953 (95%) are correct. Although 167 of the predictions are incorrect, only 8 of these errors of prediction involve a difference greater than 2%. In total, 4125 of the 4400 predictions (96%) following from the first hypothesis are correct.

One might have expected hypothesis 1 to fail in cases where x, y, and z have the same dot-and-dash pattern. For example, since the tones of O_1, (-1-1-), and O_4, (-3-3-), are evenly spaced, whereas the tones of O_2, (-1-3-) are unevenly spaced, one might have predicted that O_1 would be confused more often with O_4 than with O_2. The data, however, support the hypothesis in this instance and in all other instances in which x, y, and z have the same dot-and-dash pattern.

Let us now consider predictions in which x, y, and z have the same pattern of silent intervals. Since there are four possible patterns of silences, the signals can be divided into 4 subsets on the basis of their patterns of silences. Subset 1 contains the 8 signals whose alphabetic equivalents have 1's as subscripts, i.e., the 8 signals which are also in the IMC. Subsets 2, 3, and 4 contain the signals whose alphabetic equivalents have 2's, 3's, and 4's, respectively, as subscripts.

Hypothesis 1 leads to 144 predictions among the signals of each subset. The number of correct predictions for subsets 1, 2, 3, and 4, respectively, are 141, 142, 139, and 136. Furthermore, the number of correct predictions among the signals of subset 1, 141, is quite close to the number of correct predictions among these signals in Rothkopf's study, 140. Thus the validity of hypothesis 1 is not affected by the difference in the particular pattern of silent intervals nor by the context of other alternatives.

Two matrices that have been predicted to be simplexes appear in Table 13. Since the predictions relevant to the first hypothesis are almost always correct, there are very few violations of the simplex patterns.

Having shown that the data strongly support hypothesis 1, let us now focus our attention on hypothesis 2. Of the 7712 predictions following directly from the second hypothesis, 7118 (91%) are in accord with the data. Again, however, very few of the errors of prediction involve differences greater than 2%.

For each of the four subsets described above, hypothesis 2 leads to 96 predictions of relative confusability. The number of correct predictions among the signals of subset 1, 92, is only slightly

TABLE 13

Two Approximate Simplexes in the Total Data Matrix

		S_1	S_2	R_2	G_2	G_4	O_4
•|•|•	S_1	97	79	28	02	03	02
•|•3•	S_2	44	94	62	07	02	02
•|-3•	R_2	05	31	95	53	06	01
-|-3•	G_2	01	08	46	93	57	19
-3-3•	G_4	01	02	07	59	97	51
-3-3-	O_4	00	02	00	35	75	97

		S_1	D_1	K_1	K_3	K_4	O_4
•|•|•	S_1	97	66	31	02	01	02
-|•|•	D_1	47	96	94	05	02	00
-|•|-	K_1	07	69	95	46	06	01
-|•3-	K_3	02	11	61	97	67	02
-3•3-	K_4	01	02	07	75	98	53
-3-3-	O_4	00	01	01	03	53	97

greater than the number of correct predictions for these signals in the Morse Code context, 88. Thus, although the percentage of "same" judgment in the current experiment differs considerably from the percentages obtained by Rothkopf for these pairs, the relative magnitude of the percentages is quite similar in the two experiments. The number of correct predictions for subsets 2, 3, and 4 are 94, 91, and 83, respectively.

Violations of the second hypothesis are most likely to occur when x, y, and z have the same temporal length. In these cases 674 of the 768 predictions (88%) are correct.

Table 14 shows two matrices which have been predicted to be double simplexes. We can observe that the four 4 x 4 submatrices of each matrix are approximately simplexes and that the values in the cells of submatrix 1 and 4 are generally greater than the values in the corresponding cells of submatrices 2 and 3. Thus, both matrices in Table 14 are approximately double simplexes.

B. Other Patterns of Confusion Among the Morse-like Rhythmic Patterns

As in Rothkopf's experiment, signals that differ on a single component (particularly the final component) are confused with each other more often than signals differing in any other way. The mean confusion rate for the 160 ordered pairs of this type is 56%. A breakdown of the average confusion rate for differences on each of the 5 components is as follows:

Differ on only the fifth component -- 74%

Differ on only the fourth component -- 61%

Differ on only the third component -- 57%

Differ on only the first component -- 50%

Differ on only the second component -- 37%

TABLE 14

Two Approximate Double Simplexes in the Total Data Matrix

		D_1	K_1	K_2	K_4	R_1	W_1	W_2	W_4
-1•1•	D_1	96	94	26	02	69	33	11	03
-1•1-	K_1	69	95	74	06	33	69	26	06
-1•3-	K_2	07	54	98	37	05	22	48	15
-3•3-	K_4	02	07	27	98	00	02	11	16
•1-1•	R_1	50	62	11	05	94	72	30	01
•1-1-	W_1	42	76	49	09	64	94	69	06
•1-3-	W_2	09	39	64	19	24	62	94	14
•3-3-	W_4	02	06	09	59	03	06	38	93

		S_3	R_3	W_3	O_3	S_2	R_2	W_2	O_2
•3•1•	S_3	94	59	16	05	69	31	09	01
•3-1•	R_3	29	94	84	55	10	40	28	05
•3-1-	W_3	14	72	94	76	04	21	36	34
-3-1-	O_3	01	36	29	56	02	09	17	52
•1•3•	S_2	69	27	10	01	94	62	38	00
•1-3•	R_2	19	33	33	07	31	95	86	12
•1-3-	W_2	05	19	44	34	07	69	94	41
-1-3-	O_2	02	07	19	60	00	07	55	94

Observe that on the average there are more "same" responses when signals differ on the final component than when they differ on any other single component. Furthermore, there are more confusions when signals differ on the second tone (the third component) than when they differ on the first tone (the first component); and there are also more confusions when signals differ on the second silent interval (the fourth component) than on the first silent interval (the second component). It is somewhat surprising to observe that differences on the second component, a silence, are easier to detect than differences on any other component. This demonstrates the important role of the silence, or rhythmic, pattern in the perceptual process.

The order in which the signals of certain pairs are presented has a considerable effect on the probability of confusing the signals of these pairs. If $x < y$ and in addition $d(x) < d(y)$, then x and y are much more likely to be confused if x is presented before y than if y is presented before x, particularly if y is not more than 4 units (in temporal length) longer than x. If $x < y$, $d(x) < d(y)$, and y is two units longer than x, then $p(x,y) > p(y,x)$ 43 times, $p(x,y) = p(y,x)$ 1 time, and $p(x,y) < p(y,x)$ 4 times. The mean of these $p(x,y)$'s is 69%, whereas the mean of these $p(y,x)$'s is 52%. If $x < y$, $d(x) < d(y)$, and y is 4 units longer than x, then $p(x,y) > p(y,x)$ 49 times, $p(x,y) = p(y,x)$ 6 times, and $p(x,y) < p(y,x)$ 17 times. The mean of these $p(x,y)$'s is 17%, whereas the mean of these $p(y,x)$'s is 10%.

It is interesting to note that if $x < y$ and $d(x) = d(y)$, then the mean probability of confusing x and y is 41%, irrespective of the order in which x and y are presented. Thus, although there is a positive "time-error" associated with the duration of the tones of signals, there is no such effect associated with the duration of silent intervals of signals.

The next most common kind of misperception is the confusion of signals that have the same combination of components, but differ in terms of an inversion of a pair of tones or a pair of silences. Although the signals of each pair in this category always have the same temporal length and differ on two components, the converse is not true. In order for a pair of signals to be in this category, the signals must differ on either the first and third, the first and fifth, the third and fifth, or the second and fourth components. For example (-1.3-, .1-3-), (.3.3-, -3.3.), (.1-1., .1.1-) and (.1.3., .3.1.) are in this category. The average percentage of "same" judgments for the 64 ordered pairs in this category is 50%. The percentages corresponding to each of the four subcategories is as follows:

Inversion of third and fifth components -- 56%,

Inversion of first and fifth components -- 54%,

Inversion of first and third components -- 46%,

Inversion of second and fourth components -- 45%.

We can see that the later in the signal the inversion of a pair of tones occurs, the higher the likelihood that Ss will fail to notice that the signals differ. We can also observe that Ss detect a difference in the order of the silences slightly better than a difference in the order of the tones.

The third most common kind of confusion involves pairs of signals which have the same temporal length, but which differ on one tone and one silence. The average percentage of confusions for pairs of signals in this category is 42%. The breakdown of the percentages into the six subcategories is as follows:

Signals differ on the third and fourth components -- 61%,

Signals differ on the fourth and fifth components -- 57%,

Signals differ on the first and fourth components -- 37%,

Signals differ on the first and second components -- 36%,

Signals differ on the second and third components -- 31%,

Signals differ on the second and fifth components -- 29%.

Before concluding this section I shall point out some "interactions" between the tones and silences of signals.

(1) Ss confuse signals differing on a single component, a silence, more often if a dash, rather than a dot, precedes the silence on which they differ.

(2) Ss confuse signals differing on a single component, a silence, more often if a dash rather than a dot follows the silence on which they differ.

(3) Ss confuse signals differing on a single component, a tone, more often if a short silence rather than a long silence precedes the tone on which they differ.

C. Effects of Practice on the Perception of the Signals

In the experimental design it was pointed out that since each pair of signals was presented to one group during the first third of its experimental session, to another group during the middle third of its experimental session, and to still another group during the final third of its experimental session, systematic changes in the patterns of confusion over the course of the experiment could be investigated. Tables 15, 16, and 17 show the percentage of "same" responses to all signal pairs during the first, middle, and final thirds of the experiment, respectively. In other words, the percentages in Tables 15 - 17

Table 15 The percentage of "same" judgments obtained during the first third of each experimental session for the 32 Morse-like rhythmic patterns.

		S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	
•1•1•	S_1	100	83	61	03	94	19	14	03	83	33	08	00	72	17	00	90	14	03	00	00	33	00	06	00	08	03	03	00	00	00	00	00	S_1
•1•3•	S_2	42	94	86	42	67	86	69	17	69	56	35	03	78	67	58	22	44	56	17	44	47	31	33	00	31	06	03	03	00	00	00	03	S_2
•3•1•	S_3	47	78	97	50	56	64	69	08	53	44	67	17	67	31	50	42	28	22	06	03	25	06	69	03	31	03	06	03	08	00	00	00	S_3
•3•3•	S_4	00	25	25	94	11	19	61	83	08	25	72	75	00	42	19	42	11	14	44	08	00	06	42	39	17	33	19	42	08	19	25	03	S_4
•1•1–	U_1	75	72	53	08	97	47	47	00	89	69	11	00	81	22	08	03	97	08	00	00	81	11	08	03	42	06	00	00	17	00	03	03	U_1
•1•3–	U_2	00	67	44	25	44	92	72	14	50	42	13	03	28	53	42	08	81	75	22	03	75	61	47	11	44	22	08	00	36	11	25	00	U_2
•3•1–	U_3	03	33	56	17	14	17	97	36	50	19	11	28	17	33	58	19	53	36	75	22	64	28	83	14	44	08	19	00	36	06	14	00	U_3
•3•3–	U_4	00	03	06	67	00	17	56	100	03	22	53	61	08	19	14	22	28	53	69	61	19	28	33	06	19	56	22	17	47	28	64	08	U_4
•1–1•	R_1	42	56	22	08	86	53	33	11	94	61	36	22	58	64	36	03	69	47	22	00	78	14	17	06	53	25	14	00	19	00	06	14	R_1
•1–3•	R_2	03	47	28	19	28	53	31	25	47	97	31	36	19	47	28	28	56	97	47	19	28	42	28	00	50	58	31	06	61	00	11	00	R_2
•3–1•	R_3	06	19	50	36	03	17	11	47	42	56	94	69	03	53	69	42	33	39	81	08	36	42	33	28	44	44	72	11	33	06	72	03	R_3
•3–3•	R_4	03	03	03	50	03	03	11	39	08	56	81	97	00	28	39	69	31	25	58	58	17	31	11	39	25	50	50	53	25	31	56	00	R_4
–1•1•	D_1	44	53	50	00	83	14	25	03	83	11	31	00	97	47	58	11	36	19	00	03	94	31	25	00	69	14	00	03	08	00	03	00	D_1
–1•3•	D_2	14	42	06	22	25	50	19	19	33	61	53	28	75	97	50	50	33	58	28	06	61	67	44	47	75	89	31	11	58	47	19	00	D_2
–3•1•	D_3	00	44	36	11	08	33	61	06	08	33	36	19	28	61	97	72	08	11	22	03	67	25	94	14	42	25	33	06	03	03	14	00	D_3
–3•3•	D_4	00	00	00	47	03	06	31	44	19	06	28	31	11	22	64	97	22	08	39	44	03	28	67	94	56	25	81	56	53	42	75	06	D_4
•1–1–	W_1	00	17	31	14	44	42	39	22	72	72	44	28	42	50	11	11	97	69	39	06	94	58	19	08	86	69	14	03	58	44	14	00	W_1
•1–3–	W_2	00	14	06	03	17	56	31	22	31	75	19	06	08	47	28	11	47	94	50	14	31	72	44	19	36	69	17	03	67	36	56	11	W_2
•3–1–	W_3	00	03	19	25	03	28	61	81	17	28	69	61	06	17	19	56	56	47	92	33	22	47	39	75	53	50	72	33	61	42	78	28	W_3
•3–3–	W_4	00	00	00	22	00	03	08	58	06	14	19	58	00	03	08	58	08	33	47	94	08	08	11	42	31	58	56	72	42	67	86	75	W_4
–1•1–	K_1	08	25	14	03	61	47	36	08	42	50	42	03	78	72	47	22	75	28	17	08	97	81	44	06	89	58	22	03	72	22	06	00	K_1
–1•3–	K_2	00	14	06	03	03	31	28	14	06	28	17	11	03	78	19	44	25	61	19	17	64	100	36	50	39	69	22	19	69	81	44	06	K_2
–3•1–	K_3	03	06	22	03	00	39	72	14	11	14	17	08	14	36	81	58	22	17	11	14	78	39	97	72	25	39	81	14	36	08	56	03	K_3
–3•3–	K_4	03	00	03	06	00	00	14	14	00	03	06	13	03	11	22	94	03	17	25	19	06	39	86	100	06	33	58	36	58	47	89	53	K_4
–1–1•	G_1	03	06	08	17	14	17	11	22	56	42	50	25	53	89	42	50	89	36	44	25	75	58	28	06	97	97	33	08	92	42	64	00	G_1
–1–3•	G_2	00	06	00	03	03	11	19	14	17	25	31	33	11	61	17	72	36	44	53	31	39	50	31	69	86	94	72	72	89	69	58	28	G_2
–3–1•	G_3	00	00	06	08	17	06	22	14	06	03	64	33	03	33	72	67	14	33	56	31	47	25	67	69	58	44	100	64	17	53	83	31	G_3
–3–3•	G_4	03	00	00	00	00	00	03	44	03	03	14	39	03	03	03	81	11	03	22	36	11	17	11	78	44	67	83	100	22	64	86	58	G_4
–1–1–	O_1	00	00	03	19	11	03	08	39	17	17	31	06	06	19	11	44	31	17	50	42	53	56	33	47	89	92	36	19	97	78	67	06	O_1
–1–3–	O_2	00	00	00	03	00	00	08	25	00	17	11	06	03	42	03	39	17	67	28	58	08	58	19	42	36	42	36	61	92	97	86	67	O_2
–3–1–	O_3	00	06	00	03	00	03	06	19	00	08	53	25	00	06	36	56	14	08	42	42	28	28	42	86	28	31	83	86	78	61	100	75	O_3
–3–3–	O_4	00	03	00	06	03	03	00	03	00	00	00	19	00	00	00	00	00	03	06	64	00	00	03	58	08	42	31	83	08	69	94	100	O_4
		S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	

Table 16 The percentage of "same" judgments obtained during the middle third of each experimental session for the 32 Morse-like rhythmic patterns.

	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	
·|·|·S_1	97	69	22	06	92	19	08	00	83	31	03	00	69	11	03	00	17	00	00	00	44	00.	00	00	00	03	03	03	08	00	03	03	S_1
·|·3·S_2	50	92	56	17	44	86	33	17	69	58	25	00	47	47	39	17	28	36	03	03	31	22	19	00	14	11	11	06	11	00	03	03	S_2
·3·|·S_3	42	75	94	42	33	42	94	14	47	14	56	06	42	39	61	08	19	06	25	03	17	03	22	03	19	06	00	03	00	00	08	00	S_3
·3·3·S_4	03	28	47	97	00	19	42	69	00	03	58	53	00	22	22	53	08	06	14	03	08	11	14	42	03	17	17	44	11	03	14	03	S_4
·|·|–U_1	56	58	36	03	100	61	19	00	92	36	06	06	78	17	08	03	92	25	06	06	81	08	11	00	08	06	03	00	19	00	00	00	U_1
·|·3–U_2	06	75	28	06	28	97	33	28	39	42	17	03	11	58	14	08	61	69	28	08	64	42	25	11	17	14	17	11	06	06	11	08	U_2
·3·|–U_3	00	33	47	25	06	42	97	39	19	06	50	14	11	14	39	17	33	36	56	14	42	25	61	08	31	00	22	06	19	00	17	03	U_3
·3·3–U_4	00	06	00	47	00	11	50	94	03	14	42	42	03	11	06	28	08	08	61	64	14	28	28	78	31	33	14	14	17	28	33	17	U_4
·|–|·R_1	19	33	25	08	67	53	17	08	92	64	31	03	42	42	22	14	78	14	17	00	58	14	14	06	53	14	11	03	17	00	06	11	R_1
·|–3·R_2	03	36	14	11	08	33	19	11	33	97	19	17	06	47	19	33	61	78	31	08	25	28	22	06	61	50	14	00	14	08	11	03	R_2
·3–|·R_3	08	08	31	14	08	08	50	31	42	19	92	61	14	22	36	25	17	19	94	19	17	31	50	33	33	14	67	19	11	03	39	03	R_3
·3–3·R_4	03	03	06	28	00	06	19	25	08	39	61	94	06	22	11	47	14	25	39	56	00	11	06	39	22	25	47	53	08	25	58	03	R_4
–|·|·D_1	56	42	17	06	72	19	17	00	61	47	14	00	97	42	50	08	36	03	00	06	97	28	25	06	67	17	03	08	03	00	06	00	D_1
–|·3·D_2	03	47	11	17	06	31	11	17	31	25	31	11	42	94	42	64	28	31	14	06	44	92	42	33	72	67	36	06	33	28	14	00	D_2
–3·|·D_3	03	08	22	06	00	36	28	06	06	14	42	03	33	50	94	47	14	06	06	00	39	11	97	19	25	19	47	06	08	06	25	00	D_3
–3·3·D_4	00	03	03	22	03	06	25	42	00	11	14	47	03	28	64	94	14	03	19	31	06	06	53	72	11	19	72	53	19	17	64	03	D_4
·|–|–W_1	03	31	14	06	31	58	39	06	61	72	17	17	36	44	28	14	89	75	39	08	78	53	17	08	53	42	19	08	78	31	06	00	W_1
·|–3–W_2	06	06	00	03	06	53	22	28	22	72	25	11	14	36	11	25	69	92	42	19	47	64	17	19	28	67	22	03	50	53	28	06	W_2
·3–|–W_3	03	00	17	14	00	08	47	50	19	14	86	28	00	06	14	47	19	39	94	58	06	25	28	36	39	61	56	28	53	31	72	39	W_3
·3–3–W_4	00	03	03	17	06	00	00	42	03	08	14	56	03	00	08	61	06	36	64	89	00	06	14	58	14	39	31	69	28	56	64	69	W_4
–|·|–K_1	14	14	08	03	36	44	25	03	25	44	31	06	67	50	56	11	72	14	17	06	94	72	64	03	53	36	06	00	58	14	11	03	K_1
–|·3–K_2	00	17	00	00	03	08	11	03	03	25	17	06	17	72	25	14	11	47	17	14	61	97	47	33	31	33	31	22	33	69	28	08	K_2
–3·|–K_3	03	00	11	03	03	19	53	03	06	08	17	06	14	17	86	36	03	11	19	00	44	11	97	58	14	08	86	06	17	14	75	03	K_3
–3·3–K_4	00	03	06	08	03	06	06	39	00	03	06	11	06	11	25	83	03	06	14	14	11	17	75	97	06	28	58	44	25	28	78	67	K_4
–|–|·G_1	00	03	00	08	06	17	19	17	50	50	42	08	50	72	25	28	75	14	39	08	75	50	17	06	92	81	11	14	75	22	25	08	G_1
–|–3·G_2	03	17	00	08	08	08	03	11	11	42	17	25	08	56	00	47	28	47	28	17	31	31	11	33	64	94	61	58	64	72	47	06	G_2
–3–|·G_3	03	03	03	03	03	08	08	03	03	03	56	14	03	17	69	56	03	00	67	25	19	08	69	42	39	39	94	44	17	44	92	08	G_3
–3–3·G_4	00	03	00	06	03	03	03	11	03	11	11	28	00	00	08	61	03	11	19	36	06	06	11	56	19	53	69	97	17	53	75	50	G_4
–|–|–O_1	03	00	08	11	08	03	14	28	08	06	25	11	00	06	08	25	22	19	28	22	44	39	31	22	69	75	25	11	97	86	44	11	O_1
–|–3–O_2	00	00	03	00	03	06	06	06	06	00	03	11	03	08	03	14	22	39	11	28	06	61	14	42	36	69	22	50	72	94	42	50	O_2
–3–|–O_3	00	00	00	03	00	03	11	14	03	08	31	14	00	08	19	33	03	17	22	19	11	22	53	64	14	08	67	44	53	53	97	39	O_3
–3–3–O_4	00	03	03	08	03	00	00	14	00	00	00	14	03	06	00	06	00	06	06	36	00	03	06	36	08	33	25	58	06	64	92	97	O_4
	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	

Table 17 The percentage of "same" judgments obtained during the final third of each experimental session for the 32 Morse-like rhythmic patterns.

	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	
•|•|•S_1	94	83	50	00	97	14	11	03	78	22	03	00	56	06	00	00	17	00	00	00	17	06	00	00	08	00	00	06	00	03	03	03	S_1
•|•3•S_2	42	97	67	17	50	81	33	00	53	61	19	06	44	47	19	11	25	22	11	00	44	14	11	00	14	06	00	00	00	00	00	00	S_2
•3•|•S_3	39	56	92	50	25	53	89	17	50	33	56	14	36	31	50	31	22	03	17	00	25	00	44	03	03	06	03	00	11	03	06	00	S_3
•3•3•S_4	03	31	58	97	03	11	61	81	03	17	42	50	06	19	17	47	00	03	25	14	06	06	08	25	00	19	19	22	17	03	08	03	S_4
•|•|−U_1	58	42	44	00	97	75	39	00	78	39	03	03	64	25	08	03	83	08	06	08	58	08	03	00	19	06	06	00	11	00	00	03	U_1
•|•3−U_2	03	47	17	31	44	94	31	39	42	33	31	03	06	44	17	08	56	86	14	00	44	42	31	22	25	06	03	03	17	06	06	00	U_2
•3•|−U_3	08	22	64	08	08	28	92	28	19	17	42	14	25	17	58	08	39	17	61	17	50	14	56	25	31	06	28	00	31	08	06	06	U_3
•3•3−U_4	00	03	06	22	03	14	50	94	06	25	50	61	08	08	17	33	00	22	47	75	17	31	17	53	17	14	22	11	14	22	33	14	U_4
•|−|•R_1	19	36	22	06	67	50	17	03	97	67	33	11	50	42	08	11	69	28	06	03	50	06	06	03	47	08	11	03	31	00	00	03	R_1
•|−3•R_2	08	11	17	00	11	28	25	06	44	94	50	28	19	47	25	36	61	83	22	05	03	39	03	00	25	50	19	11	08	25	00	00	R_2
•3−|•R_3	00	03	06	31	03	25	42	33	44	44	94	64	08	17	50	14	17	25	78	28	19	19	44	28	36	14	47	03	17	06	53	03	R_3
•3−3•R_4	00	03	03	14	00	08	19	22	14	53	56	92	00	19	11	28	03	14	11	69	06	08	00	17	14	42	36	78	17	33	42	06	R_4
−|•|•D_1	42	33	17	03	69	06	06	03	64	33	06	00	94	14	42	03	28	11	00	00	92	19	19	00	64	25	06	00	17	03	08	00	D_1
−|•3•D_2	00	53	11	17	11	36	22	14	19	42	19	17	22	92	33	39	17	17	03	03	47	78	25	22	61	64	33	11	36	31	14	00	D_2
−3•|•D_3	00	06	31	03	03	39	19	03	06	17	28	00	17	42	89	61	06	03	19	00	36	19	100	11	25	19	61	03	03	03	22	03	D_3
−3•3•D_4	03	00	06	08	03	03	19	39	03	06	06	11	06	33	72	100	03	06	17	17	06	22	36	75	17	22	81	72	28	17	61	00	D_4
•|−|−W_1	06	14	22	08	44	53	22	28	58	75	14	14	47	25	11	08	94	64	14	06	56	36	17	11	64	50	03	06	75	19	06	00	W_1
•|−3−W_2	00	03	08	06	19	53	11	17	19	58	11	03	06	28	17	03	69	94	39	08	39	56	25	17	17	31	19	03	61	33	22	19	W_2
•3−|−W_3	00	08	06	06	03	08	44	50	08	22	61	33	00	03	22	31	22	22	92	61	08	14	28	36	19	47	42	25	36	31	78	28	W_3
•3−3−W_4	00	03	06	36	00	06	06	39	00	19	22	50	03	14	11	31	03	44	58	94	08	14	11	50	22	28	28	53	31	39	58	78	W_4
−|•|−K_1	00	19	03	03	33	22	19	06	33	25	25	06	64	44	39	14	58	36	17	06	94	69	31	08	69	42	06	00	69	11	08	00	K_1
−|•3−K_2	03	08	03	00	03	19	14	03	06	17	08	03	03	53	31	36	31	36	06	14	33	97	17	28	42	39	42	11	17	67	39	08	K_2
−3•|−K_3	00	00	17	03	08	19	42	11	03	11	06	11	06	14	72	44	17	11	08	03	61	33	97	69	14	03	69	17	28	06	72	00	K_3
−3•3−K_4	00	00	03	06	00	08	06	42	00	00	08	14	00	08	36	67	00	11	06	14	06	25	64	97	03	22	53	31	14	28	83	39	K_4
−|−|•G_1	00	17	03	06	06	08	03	14	42	53	50	22	47	78	42	36	69	19	36	06	83	50	36	31	89	92	22	11	81	36	25	03	G_1
−|−3•G_2	00	03	03	03	03	03	08	08	03	44	33	33	06	56	08	42	25	39	28	17	14	44	28	31	64	92	44	42	67	72	44	22	G_2
−3−|•G_3	00	00	06	00	03	00	03	19	00	06	50	19	08	31	61	58	06	06	53	08	19	14	36	25	31	28	94	53	08	31	42	11	G_3
−3−3•G_4	00	03	00	08	00	06	03	11	00	08	08	39	00	00	11	44	03	11	39	28	00	11	03	31	14	58	69	94	14	25	78	44	G_4
−|−|−O_1	03	00	03	03	11	06	11	25	33	14	19	08	06	22	08	31	42	25	36	28	56	56	28	14	69	81	08	11	97	83	61	11	O_1
−|−3−O_2	00	00	03	03	00	06	08	14	06	06	08	17	03	22	03	39	25	58	17	56	11	56	08	39	33	56	17	42	75	92	53	50	O_2
−3−|−O_3	00	00	03	00	00	03	14	11	06	11	25	03	00	08	28	58	08	25	22	19	14	17	56	69	17	22	72	75	58	42	97	53	O_3
−3−3−O_4	00	00	06	03	00	00	03	11	00	00	00	17	00	00	03	08	00	08	06	25	03	11	00	64	06	31	22	83	14	58	81	97	O_4
	S_1	S_2	S_3	S_4	U_1	U_2	U_3	U_4	R_1	R_2	R_3	R_4	D_1	D_2	D_3	D_4	W_1	W_2	W_3	W_4	K_1	K_2	K_3	K_4	G_1	G_2	G_3	G_4	O_1	O_2	O_3	O_4	

are based solely on responses by Ss during the indicated block of experimental presentations.

The percentage of confusions decreased from 30.8% in the first third to 24.1% in the middle third to 23.1% in the final third of the experiment. However, it is important to note that the percentage of "same" responses to pairs in which the two signals were the same also decreased somewhat--from 97% to 95% to 94.4%. Thus, it appears that Ss learn that the signals of most pairs (91.2%) are different and change their criterion appropriately.

I would like to point out, however, that the decrease in the confusion rate is greater for certain kinds of pairs than for others. For convenience I shall refer to pairs (x,y) in which $x < y$ or $y < x$ as dominance pairs and to pairs (x,y), $x \neq y$, in which neither $x < y$ nor $y < x$ as nondominance pairs. The following is a description of the processes involved in confusing signals of both kinds of pairs.

If (x,y) is a dominance pair, then by definition, each component of the shorter signal is less than or equal to the corresponding component of the longer signal, and at least one component of the shorter signal is less than the corresponding component of the longer signal. Accordingly, if a S confuses the signals of a dominance pair, he has failed to observe that certain components of one signal are shorter than the corresponding components of the other signal.

If (x,y) is a nondominance pair, then at least one component of each signal is greater than the corresponding component of the other. For example, (.1-1-, -1.1-), (.1.3-, -1-3.), and (-1.3., .3-1-) are nondominance pairs. Observe that the signals of the first of these pairs are permutations of each other, and that the signals of the second and third pairs can be made more alike by permuting components.

In general, one of the most important ways in which signals of nondominance pairs differ is in the particular order in which the components occur. It appears, then, that a S who confuses the signals of a nondominance pair has failed to observe sequential differences between the signals.

Of the 992 pairs of nonidentical signals, 570 are nondominance pairs and 422 are dominance pairs. The mean percentage of "same" responses to nondominance pairs decreases from 32.3% for the first third of the experimental trials to 22.9% for the middle third of the trials to 21.7% for the final third of the trials. The corresponding means for the dominance pairs are 28.9%, 25.8%, and 24.9%. Thus, while the confusion rate for nondominance pairs in the final third of the experiment is only 67% of its rate in the first third, the confusion rate for dominance pairs in the final third of the experiment is 86% of its rate in the first third. These results suggest that in the course of the experimental session Ss learn to detect sequential differences relatively better than differences in component duration. Shepard (1963, p. 47) describes a somewhat similar effect associated with learning to identify the signals of the IMC.

Despite the effect described above, the basic patterns of confusion do not appear to change much during the course of the experiment. Although it is difficult to see this in Tables 15 - 17, we can observe this consistency in the submatrices shown in Tables 18 and 19. Notice the simplex structure in all three matrices of Table 18 and the double simplex structure in the matrices of Table 19. The presence of these predicted patterns indicates that the hypotheses are supported by the data from each third of the experiment.

TABLE 18

An Approximate Simplex in the Matrices
for Each Third of the Experimental Session

A. First Third of Experimental Session

	S_1	S_2	R_2	G_2	G_4	O_4
•|•|• S_1	100	83	33	03	00	00
•|•3• S_2	42	94	56	06	03	03
•|-3• R_2	03	47	97	58	06	00
-|-3• G_2	00	06	25	94	72	28
-3-3• G_4	03	00	03	67	100	58
-‾-‾- O_4	00	03	00	42	83	100

B. Middle Third of Experimental Session

	S_1	S_2	R_2	G_2	G_4	O_4
•|•|• S_1	97	69	31	03	03	03
•|•‾• S_2	50	92	55	11	06	03
•|-‾• R_2	03	36	97	50	00	03
-|-‾• G_2	03	17	42	94	58	06
-‾-‾• G_4	00	03	11	53	97	50
-‾-‾- O_4	00	03	00	33	58	97

C. Final Third of Experimental Session

	S_1	S_2	R_2	G_2	G_4	O_4
•|•|• S_1	94	83	22	00	06	03
•|•‾• S_2	42	97	61	06	00	00
•|-‾• R_2	08	11	94	50	11	00
-|-‾• G_2	00	03	44	92	42	22
-‾-‾• G_4	00	03	08	58	94	44
-‾-3- O_4	00	00	00	31	83	97

TABLE 19

An Approximate Double Simplex in the Matrices for Each Third of the Experimental Session

A. First Third of Experimental Session

		D_1	K_1	K_2	K_4	R_1	W_1	W_2	W_4
-|•|•	D_1	97	94	31	00	83	36	19	03
-|-|-	K_1	78	97	81	06	42	75	28	08
-|•3-	K_2	03	64	100	50	06	25	61	17
-3•3-	K_4	03	06	39	100	00	03	17	19
•|-|•	R_1	58	78	14	06	94	69	47	00
•|-|-	W_1	42	94	58	08	72	97	69	06
•|-3-	W_2	08	31	72	19	31	47	94	14
•3-3-	W_4	00	08	08	42	06	08	33	94

B. Middle Third of Experimental Session

		D_1	K_1	K_2	K_4	R_1	W_1	W_2	W_4
-|•|•	D_1	97	97	28	06	61	36	03	06
-|•|-	K_1	67	94	72	03	25	72	14	06
-|•3-	K_2	17	61	97	33	03	11	47	14
-3•3-	K_4	06	11	17	97	00	03	06	14
•|-|•	R_1	42	42	14	06	92	78	14	00
•|-|-	W_1	36	78	53	06	61	89	75	08
•|-3-	W_2	14	47	64	19	22	69	92	19
•3-3-	W_4	03	00	06	58	03	06	36	89

C. Final Third of Experimental Session

		D_1	K_1	K_2	K_4	R_1	W_1	W_2	W_4
-|•|•	D_1	94	92	19	00	64	28	11	00
-|•|-	K_1	64	94	69	08	33	58	36	06
-|•3-	K_2	03	33	97	28	06	31	36	14
-3•3-	K_4	00	06	25	97	00	00	11	14
•|-|•	R_1	50	50	06	03	97	69	28	03
•|-|-	W_1	47	56	36	11	58	94	64	06
•|-3-	W_2	06	39	56	17	19	69	94	08
•3-3-	W_4	03	08	14	50	00	03	44	94

If the matrices in Tables 15, 16, and 17 are similar in structure, we should also expect high correlations between corresponding rows of the three matrices as well as between corresponding columns of the three matrices. The average correlations between corresponding rows and between corresponding columns of Table 15 and 16, Tables 15 and 17, and Tables 16 and 17 are given below:

Tables 15 and 16 (first and middle thirds)

Rows --$\bar{r}$ = .893

Columns --$\bar{r}$ = .891

Tables 15 and 17 (first and final thirds)

Rows --$\bar{r}$ = .884

Columns --$\bar{r}$ = .881

Tables 16 and 17 (middle and final thirds)

Rows --$\bar{r}$ = .923

Columns -$\bar{r}$ = .922

These high correlations are evidence of considerable stability of the structure of the confusion matrix over the three stages of the experiment. Thus, despite the fact that the criterion changes, the patterns of confusion remains quite constant.

D. Multidimensional Configurations for the Morse-like Rhythmic Patterns

The configuration shown in Fig. 6 is the 2-dimensional row solution (coefficient of alienation = .17) obtained by means of G-L(SSA-II). The input to the computer was the total confusion data for the Morse-like rhythmic patterns. Observe that the vertical dimension orders the signals according to temporal length. Thus, the shortest signal, (.1.1.), is in the lowest band, whereas the longest signal is in the highest band. Furthermore, the signals within any band have a greater temporal length than those in the band below it and a shorter temporal length than those

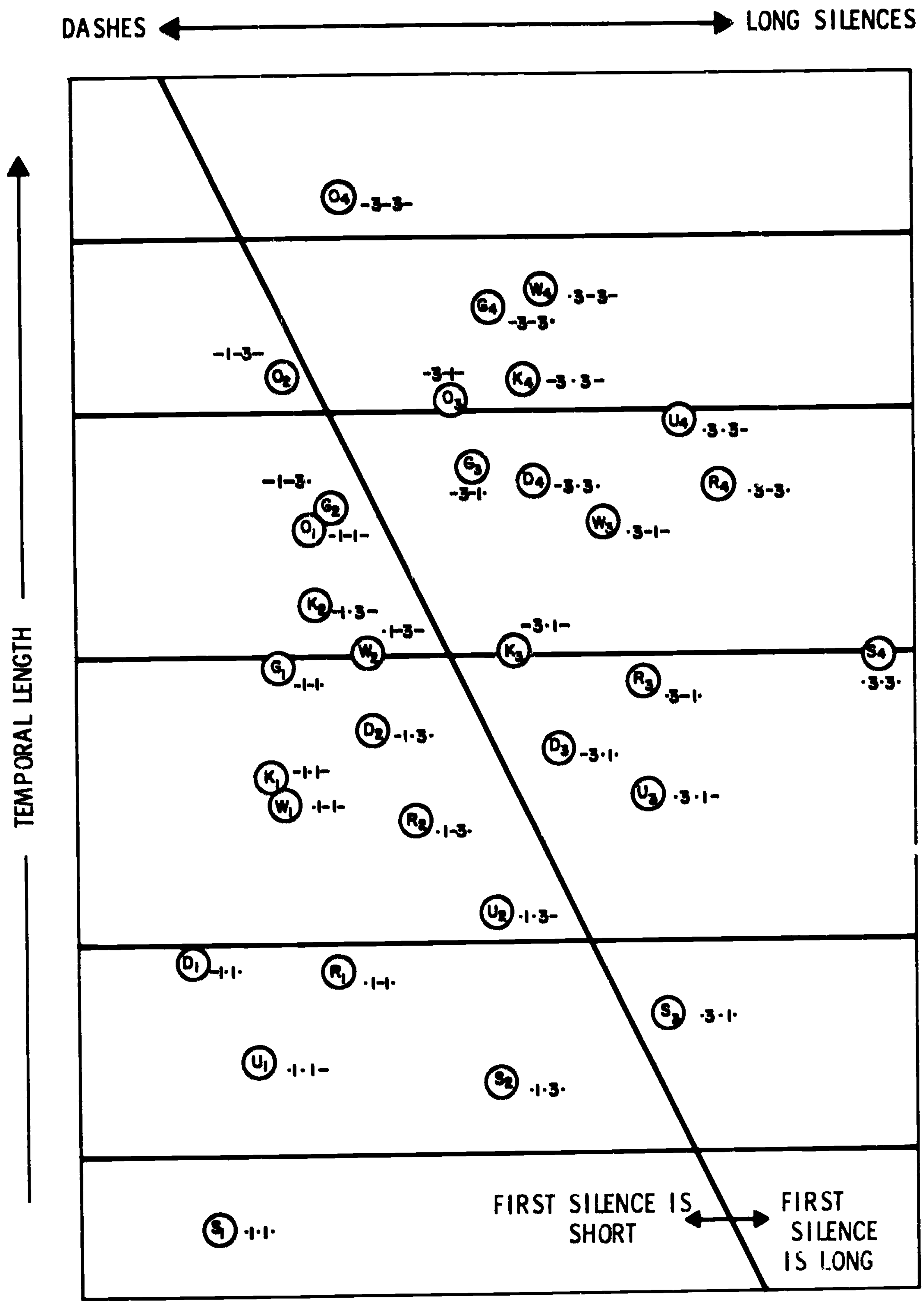


Fig. 6. A two-dimensional configuration for the 32 Morse-like rhythmic patterns - I. [Guttman-Lingoes (Smallest Space Analysis - II) row solution]

in the band above it. Within each band the signals with more dashes and more short silences are generally to the left, whereas the signals with more dots and more long silences are to the right. Accordingly, the second dimension reflects the sound-to-silence ratio for signals having the same temporal length.

It has previously been pointed out that signals differing on only the second component, i.e., the first silence, are easier to distinguish than signals which differ on any other single component. Observe that a diagonal line divides the signals on the basis of their second component. All signals whose second component is a short silence are to the left of the diagonal, whereas all signals whose second component is a long silence are to the right of the diagonal.

It has also been previously stated that signals differing on the final component alone are more likely to be confused than signals differing on any other single component. Observe that signals differing on only the last component are usually closer to each other in the figure than signals differing from each other on any other single component.

The configuration in Fig. 7 is the same as that in Fig. 6. I have, however, omitted the boundary lines in Fig. 7 and have grouped together all signals that differ only in an inversion of components. Signals within the same oval have the same temporal length, the same number of dashes, the same number of dots, the same number of long silences, and the same number of short silences. Note that groups of signals with the same number of dashes are ordered on the basis of number of long silences. For example, for each of the three groups of signals with the same number of dashes, the group of signals with one long silence is between the group with no long silences and the group

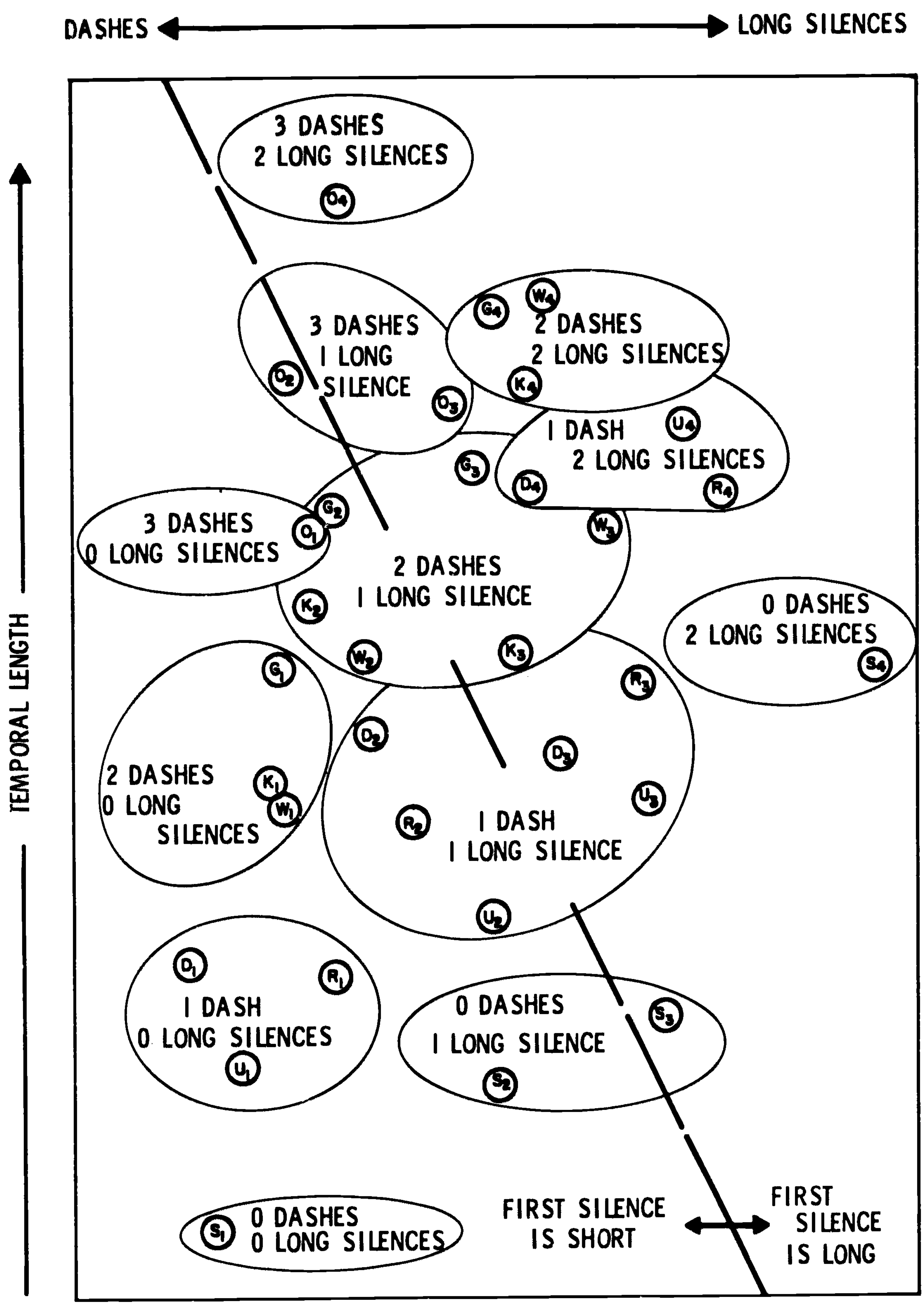


Fig. 7. A two-dimensional configuration for the 32 Morse-like rhythmic patterns - II. [Guttman-Lingoes (Smallest Space Analysis - II) row solution]

with two long silences. Similarly, the groups of signals that have the same number of long silences are ordered in Fig. 7 according to the number of dashes they have.

The two-dimensional configuration shown in Fig. 8 is the solution (stress = .23) obtained for the same data by means of the Kruskal program with the nonsymmetric option. This configuration, as well as the two-dimensional solution obtained by means of the Kruskal procedure with the symmetric option (stress = .19), the two dimensional solution obtained by means of the Guttman-Lingoes symmetric program, G-L(SSA-I), (Lingoes, 1965a),(coefficient of alienation = .20), and the two-dimensional column solution obtained by means of G-L(SSA-II), (coefficient of alienation = .20), is extremely similar to the one shown in Figs. 6 and 7, the G-L(SSA-II) row solution.

The three-dimensional solutions obtained by the several procedures mentioned above are also very similar to each other. Only the G-L(SSA-II) column solution (coefficient of alienation = .13) is shown in this paper. The first and second dimensions of this configuration are shown in Fig. 9, the first and third dimensions are shown in Fig. 10, and the second and third dimensions are shown in Fig. 11.

One can observe that Fig. 9 has the same basic structure as Figs. 6, 7, and 8. Thus, it can be seen that (1) the signals are ordered according to temporal length; (2) within each band of constant temporal length the signals with the most dashes and short silences are to the left, whereas the signals with the most dots and most long silences are to the right; and (3) a diagonal line separates the signals with a short first silence from the signals with a long first silence.

In Fig. 10 all signals to the left of the diagonal begin with a dash, whereas all signals to the right of the diagonal begin with a

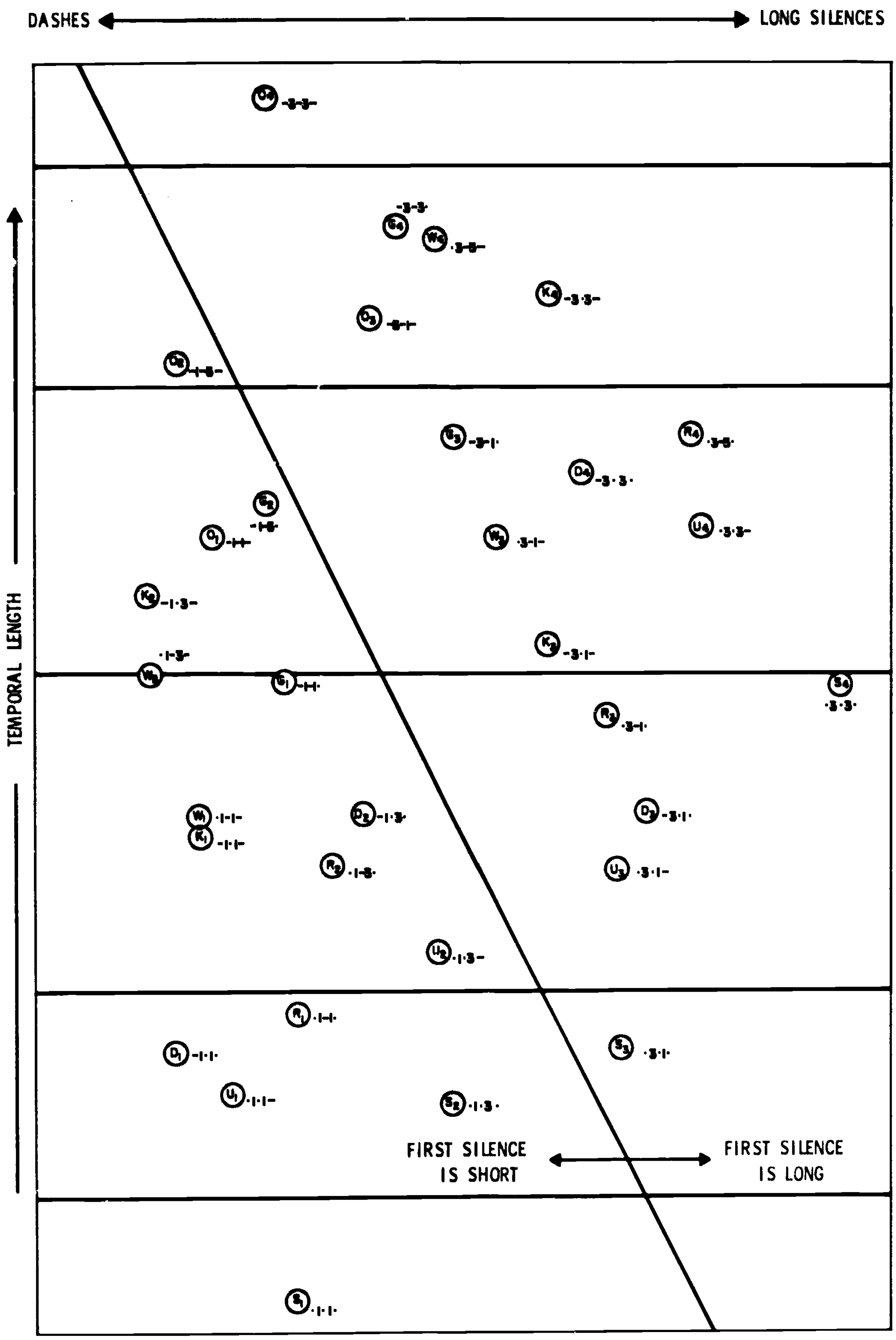


Fig. 8. A two-dimensional configuration for the 32 Morse-like rhythmic patterns - III. [Kruskal nonsymmetric solution]

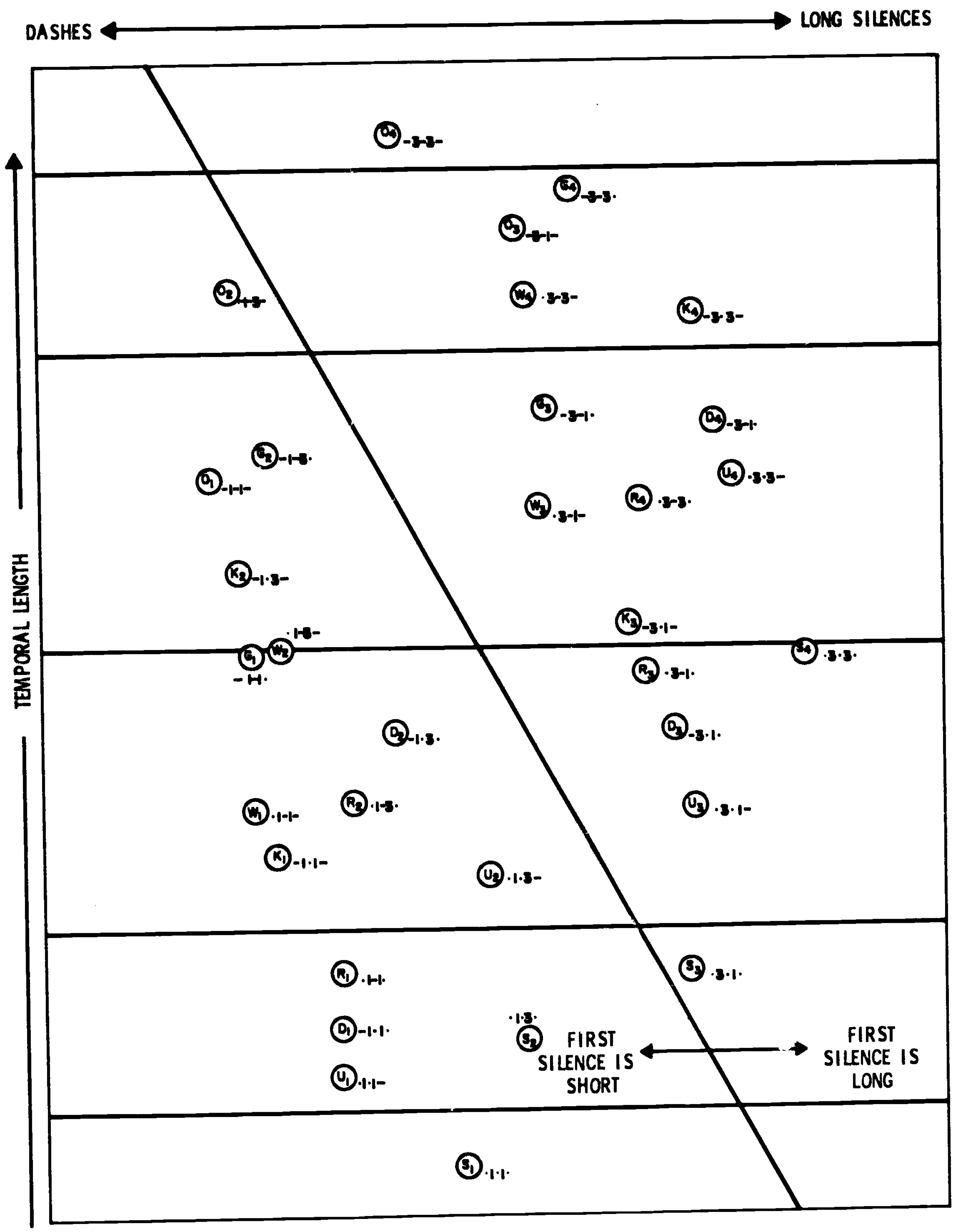


Fig. 9. First and second dimensions of a three-dimensional configuration for the 32 Morse-like rhythmic patterns. [Guttman-Lingoes (Smallest Space Analysis - II) column solution]

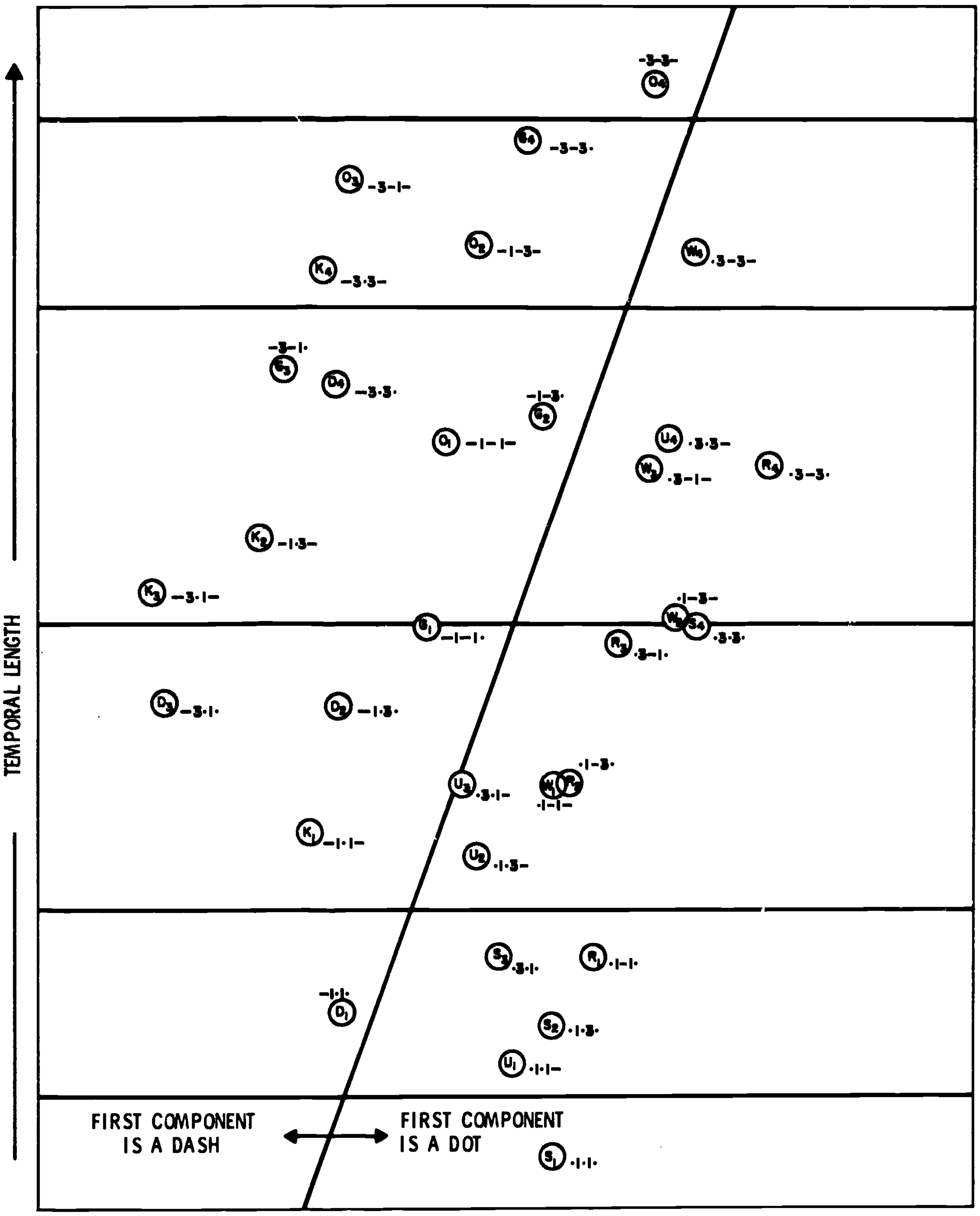


Fig. 10. First and third dimensions of a three-dimensional configuration for the 32 Morse-like rhythmic patterns. [Guttman-Lingoes (Smallest Space Analysis - II) Column Solution]

dot. Recall that differences on the first component are easier to detect than differences on any component other than the second.

In Fig. 11 the signals are divided into four groups on the basis of their first two components. The only signals out of place are O_4 and G_2. Figure 12 also shows the second and third dimensions of the configuration, but in this figure the signals beginning with three long components (two dashes separated by a long silence) and the signals beginning with three short components (two dots separated by a short silence) are omitted. Observe that signals with the same first three components are close together in the figure. Furthermore, there is a cyclical pattern among the first three components of these signals, as each boundary separates signals which differ on one of the first three components. Thus, whereas the first dimension groups and orders signals according to their temporal length, the second and third dimensions group signals according to the particular combination of components in the signals and the precise order in which the components occur in the signals.

Separate two- and three-dimensional analyses were also obtained for the data from each third of the experiment. The two-dimensional Kruskal nonsymmetric solutions obtained for the data from the first third of the experiment (stress = .264) and for the data from the final third of the experiment (stress = .280) are shown in Figs. 13 and 14, respectively. Since these configurations (as well as the 3-dimensional configurations) are so similar to those obtained for the total data, they will not be discussed.

In the next chapter the models for both sets of signals will be integrated into a single more general structural theory.

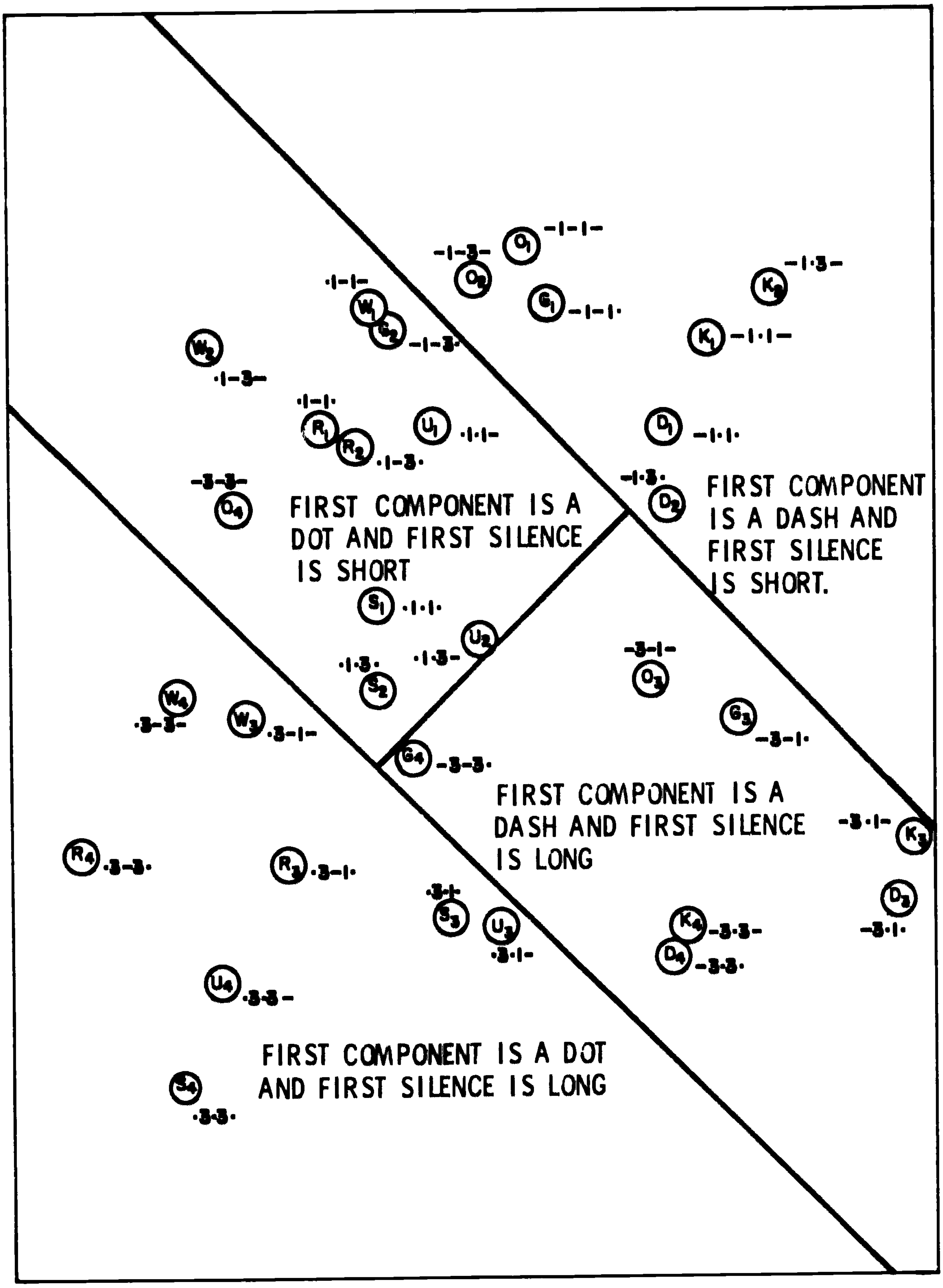


Fig. 11. Second and third dimensions of a three-dimensional configuration for the 32 Morse-like rhythmic patterns - I. [Guttman-Lingoes (Smallest Space Analysis - II) column solution]

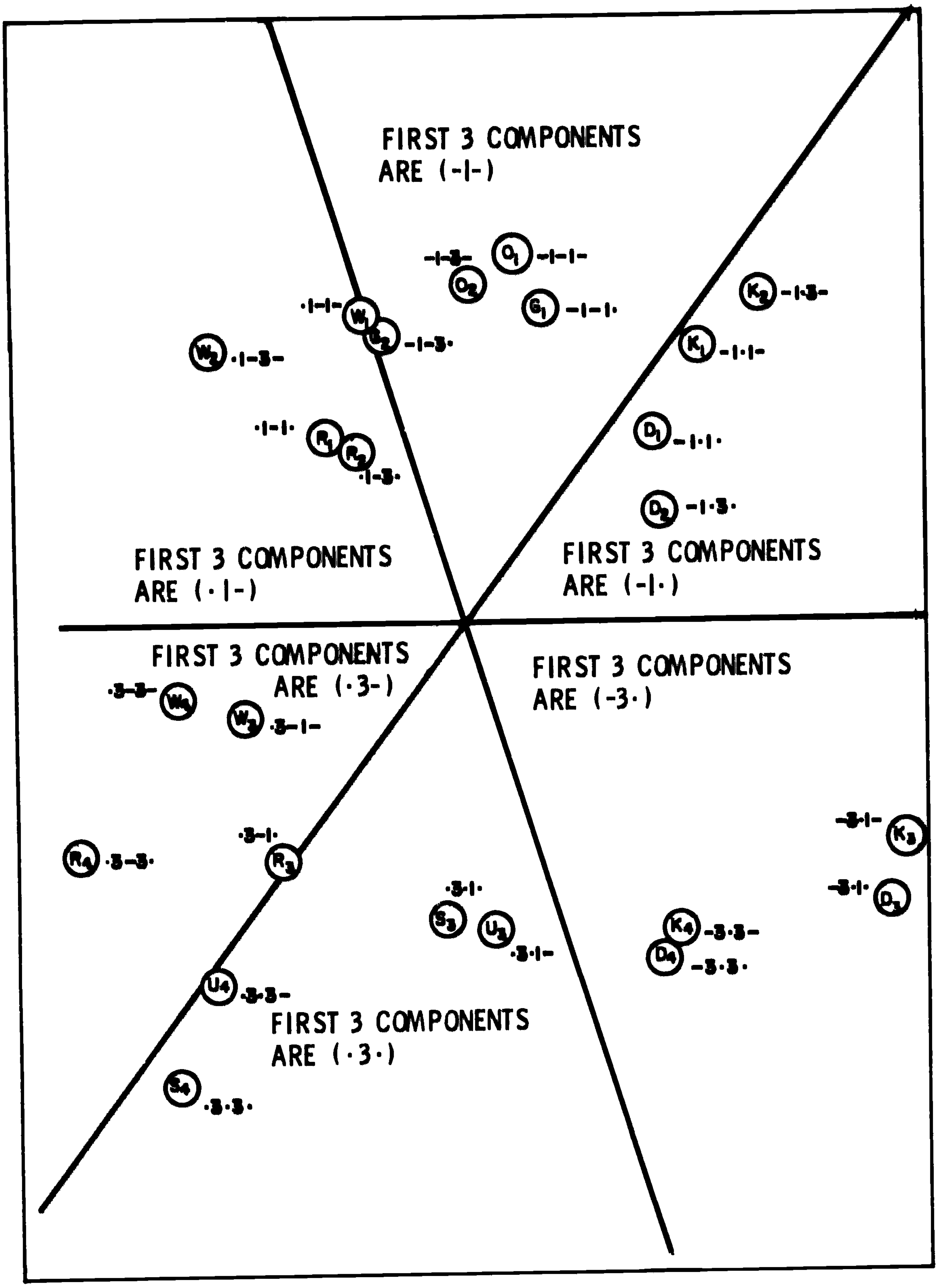


Fig. 12. Second and third dimensions of a three-dimensional configuration for the 32 Morse-like rhythmic patterns - II (signals beginning with .1. or -3- are omitted). [Guttman-Lingoes (Smallest Space Analysis - II) column solution]

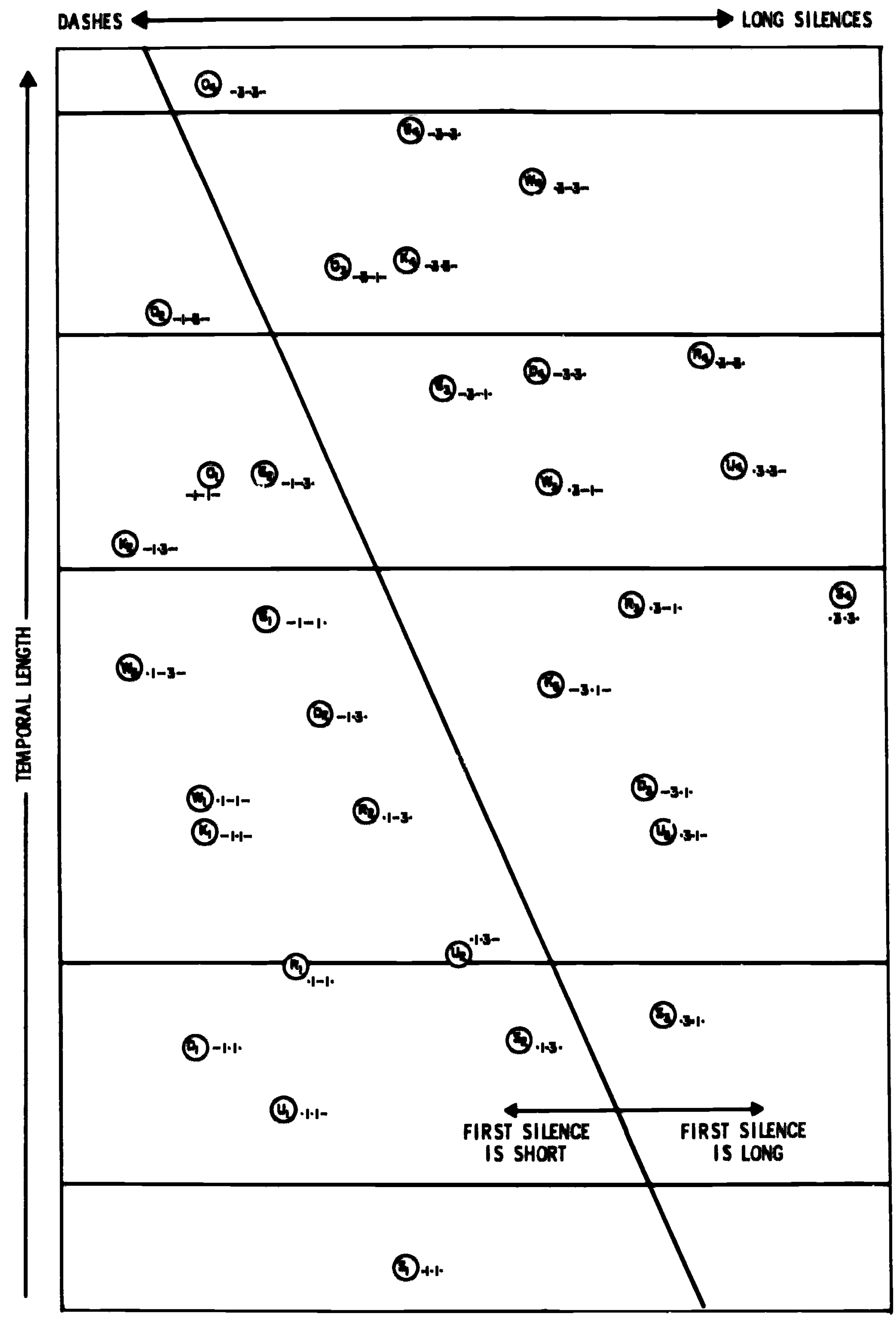


Fig. 13. A two dimensional configuration for the 32 Morse-like rhythmic patterns based on data from the first third of the experiment. [Kruskal nonsymmetric solution]

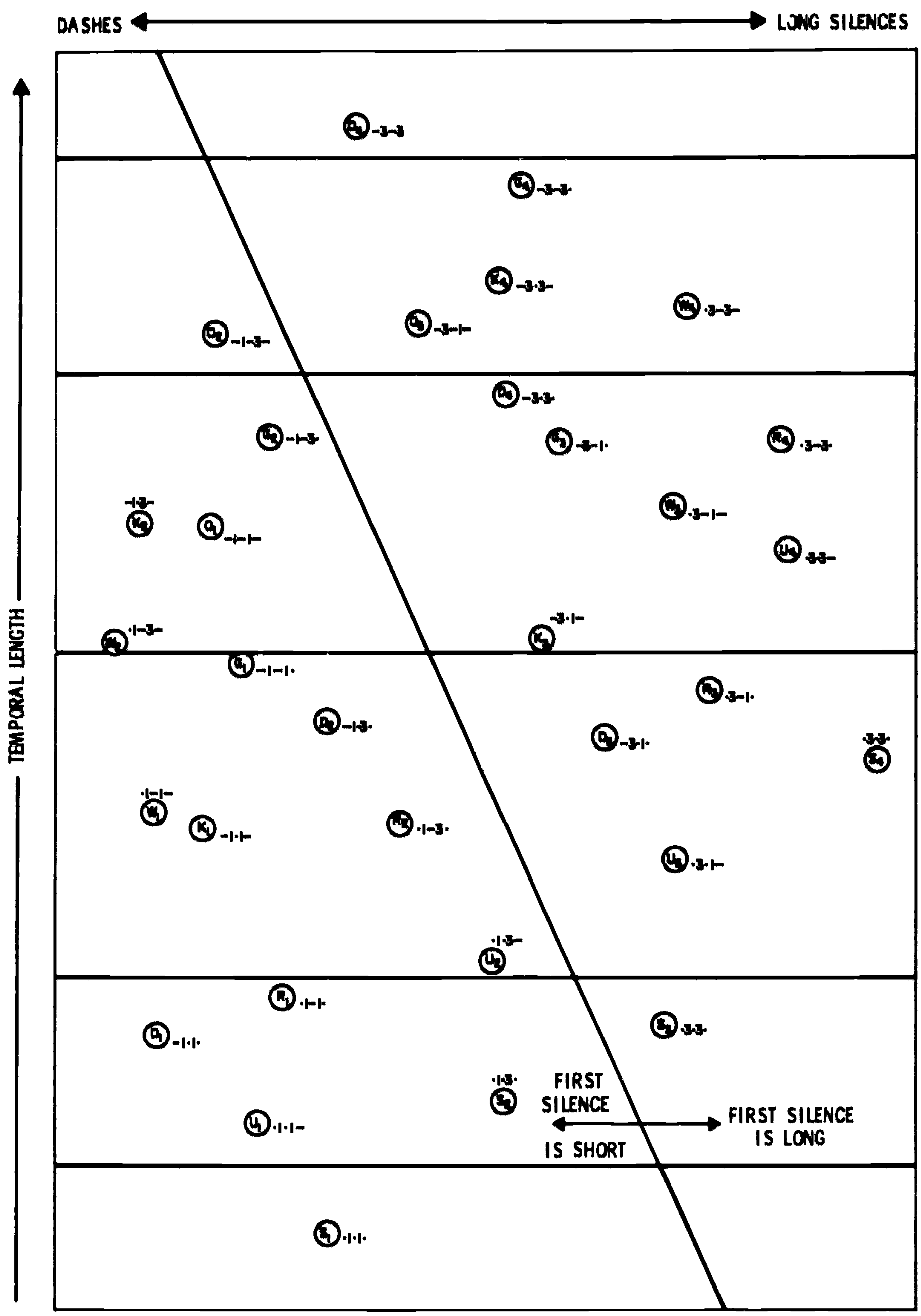


Fig. 14. A two-dimensional configuration for the 32 Morse-like rhythmic patterns based on data from the final third of the experiment. [Kruskal nonsymmetric solution]

CHAPTER 4. AN INTEGRATION OF THE FIRST AND SECOND MODELS

I. The Universe of Content

The signals first studied here varied in number of components, but all silent intervals in these signals were of the same duration. In contrast, all the signals studied in the second model had the same number of components, but the silent intervals varied in duration. Let us now consider a more general set of signals, μ_3, which includes μ_1 and μ_2 as subsets. In Cartesian product notation $\mu_3 = \Delta \cup \Delta\times\Sigma\times\Delta \cup \Delta\times\Sigma\times\Delta\times\Sigma\times\Delta \cup \Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta \cup \Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$ where Δ is a set whose elements are a 1-unit tone (a dot) and a 3-unit tone (a dash), and Σ is a set whose elements are a 1-unit silence (a short silence) and a 3-unit silence (a long silence). Since Δ and Σ have two elements each, $\Delta\times\Sigma\times\Delta$ has $2^3 = 8$ elements (four of which are in μ_1), $\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$ has $2^5 =$ 32 elements (the elements of μ_2), $\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$ has $2^7 = 128$ elements (sixteen of which are in μ_1) and $\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta\times\Sigma\times\Delta$ has $2^9 = 512$ elements (thirty-two of which are in μ_1). Since μ_3 has so many elements, 682, I shall not provide a complete list of these signals.

II. The Structural Hypotheses

The rationale for the first three hypotheses is the same as that given in the first and second models. The fourth and fifth hypotheses are motivated by the results of the experiments discussed in this thesis. In all five hypotheses p(x,y) denotes the percentage of "same" responses to the ordered pair (x,y) in the kind of task carried out by Rothkopf and the present investigator.

A. The First Hypothesis

Definition 1.

For all x, y ε μ_3, <u>x $\leq$ y</u> iff it is possible to transform x to y by applying to x one or more of the following operations:

(1) changing at least one dot to a dash;

(2) changing at least one 1-unit silence to a 3-unit silence;

(3) adding at least one tone and an equal number of silences.

The ordering among the signals of μ_1 and the ordering among the signals of μ_2 are identical to those established for these sets in the first and second models, respectively.

Definition 2.

For all x, y, z, ε μ_3, x is closer to y than to z in the ordering on μ_3 iff $x < y < z$ or $z < y < x$.

Hypothesis 1.

For all x, y z ε μ_3, if <u>x is closer to y than to z in the ordering on μ_3</u>,

then $p(x,y) > p(x,z)$;

$p(x,y) > p(z,x)$;

$p(y,x) > p(z,x)$; and

$p(y,x) > p(x,z)$.

In the results section of Chapter 2 some limitations on the first hypothesis are given.

B. The Second Hypothesis

In the following definitions d(x), s(x), and t(x) denote the number of dashes in x, the number of long silences in x, and the temporal length of x, respectively.

Definition 3.

For all x, y, z ε μ_3, <u>y is component-wise between x and z</u> iff:

(1) x, y, and z have the same number of components, and

(2) for all i, the i^{th} component of y is the same as the i^{th} component of x and/or the i^{th} component of z.

Definition 4.

For all x, y, z ε μ_3, <u>y is dash-wise between x and z</u> iff either $d(x) \leq d(y) \leq d(z)$ or $d(z) \leq d(y) \leq d(x)$.

Definition 5.

For all x, y, z ε μ_3, <u>y is silence-wise between x and z</u> iff either $s(x) \leq s(y) \leq s(z)$ or $s(z) \leq s(y) \leq s(x)$.

Definition 6.

For all x, y, z ε μ_3, y is time-wise between x and z iff either $t(x) \leq t(y) \leq t(z)$ or $t(z) \leq t(y) \leq t(x)$.

Hypothesis 2.

For all x, y, z ε μ_3, $(x \neq y \neq z)$,

if (i) y is component-wise between x and z,

(ii) y is dash-wise between x and z,

(iii) y is silence-wise between x and z,

(iv) y is time-wise between x and z, and in addition,

(v) neither $x < y < z$ nor $z < y < x$,

then $p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

C. The Third, Fourth, and Fifth Hypotheses

Hypothesis 3.

For all x, y ε μ_3, $(x \neq y)$, $p(x,x) > p(x,y)$ and $p(y,x)$.

Hypothesis 4.

If (i) x, y, and z ($x, y, z \in \mu_3$) have the same number of components

(ii) x and y differ only on the final component and

(iii) x and z differ on only one component, but not on the final component,

then $p(x,y) > p(x,z)$,

$p(x,y) > p(z,x)$,

$p(y,x) > p(z,x)$, and

$p(y,x) > p(x,z)$.

Hypothesis 5.

If (i) $x < y$, ($x, y \in \mu_3$),

(ii) $d(x) < d(y)$ and/or x has fewer components than y, and

(iii) the temporal length of x is either two or four units shorter than the temporal length of y,

then $p(x,y) > p(y,x)$.

III. Generalizations

I would predict that the five hypotheses stated above would hold for visual as well as for auditory signals. The signals could be presented visually by letting short and long light flashes represent the dots and dashes, and by letting short and long intervals between light flashes represent the short and long silent intervals. The multidimensional configuration for signals (or a sample of signals) in both modalities would probably reveal a "temporal length" dimension, a "number of components" dimension, and a "ratio of sound to silence" dimension.

It would be interesting to explore the extent to which the confusion structure is affected by the particular language spoken by the

Ss. We might find that Ss who speak a language in which the last syllable is often stressed would be able to detect differences on the final component better than differences on other components. We might also discover that the patterns of signal confusion for Ss who speak a language with little stress (such as French or Spanish) would differ considerably from the patterns of confusions for Ss who speak English. Since the signals of μ_3 can be presented to Ss who speak any language, an investigation of such group differences in the patterns of signal confusion is quite feasible.

Summary,

Chapter V,

pages 88 - 89,

available from author on request.

APPENDIX

Instructions Given to Ss Immediately before Administration of the Stimulus Lists

May I please have your attention? This is an experiment to determine how well certain signals can be told apart. You will be hearing signals which will consist of three tones each. Each tone may be either short or long. This is a short tone (.). This is a long tone (-). Most of the signals which you will hear contain both short and long tones. For example, the following signal will be presented in the experiment (-3-3.). That signal consisted of two long tones followed by a short tone.

The signals will be presented in the following way: first, one 3-toned signal, and then a pause, and then the second 3-toned signal. For example, here is a pair of signals, each with three tones--(-1.1., -1.1.). Think to yourselves whether the second signal of 3 tones sounded exactly like the first signal of 3 tones.

In this experiment you will hear many pairs of signals, and for each pair you will be asked to decide whether the second signal in the pair is the same as the first signal in the pair. Now take a look at your answer sheets. You will notice that there are two answer spaces to the right of each item. These answer spaces are labelled "Y" and "N" for "Yes" and "No" as well as "T" and "F" for "True" and "False." In this experiment when you think that the second signal is exactly the same as the first signal, you should make a mark in the Y-column for "Yes, it is the same as the first signal." If, however, the second signal does not sound exactly like the first signal, mark the item "N" for "No, it is not the same as the first signal."

The example which you were given before will now be repeated--(-1.1., -1.1.). I think you will agree that the second signal sounded exactly like the first signal. Therefore, you should mark item 1 "Yes" on your answer sheet. Observe that item 1 is marked "Yes" on the blackboard at the front of the room.

Here is example 2--(-3.3., .3.3-). Although each of these signals had one long and two short tones, the order of short and long tones in the second signal was not the same as the order of short and long tones in the first signal. Since the second signal did not sound exactly like the first signal, item 2 is marked "No" on the blackboard. Now mark item 2 "No" on your answer sheets.

Here is example 3--(.1.1., .3.3.). Although each of these signals consisted of three short tones, the second signal was not exactly the same as the first signal. In the first signal the tones were separated by short silent periods, whereas in the second signal the tones were separated by long silent periods. Since the second signal did not sound exactly like the first signal, you should mark item 3 "No" on your answer sheet. Observe that item 3 is marked "No" on the blackboard.

Here is the fourth and final example--(.3-1., .3-1.). Since the second signal sounded exactly like the first signal, item 4 is marked "Yes" on the blackboard. Now mark item 4 "Yes" on your answer sheets.

Are there any questions?

Now get ready for the experiment. To help you keep track of the item number you should be on, the item number will be announced after every group of 15 signal pairs. There will only be three seconds between items, so answer each item as quickly as possible.

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